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Numerical weather prediction model performance on instant occlusion developments

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Summary

The output of numerical weather prediction (NWP) models is recognized as an important component in the forecaster's decision-making process when the possibility of instant occlusion development is being considered. This paper presents three cases of actual or potential instant occlusion development over the North Atlantic and examines the performance of the Meteorological Office fine-mesh NWP model at these times. The cases include two different types of instant occlusion development as identified in previous studies. Manual forecasting guidelines suggested in a earlier paper are also evaluated in each case.

1. Introduction

When a polar vortex or trough approaches a front, the forecaster must consider whether there will be an interaction between these two features such that they will link up to form an instant occlusion, a synoptic feature which resembles a classical occlusion and, in many ways, behaves like one. The decision will of course have important implications for the forecasts of synoptic evolution and associated weather events which will follow. Previous studies (McGinnigle *et al.* 1988) have shown that there are two fundamental types of instant occlusion formation which have significant differences in synoptic development at the time of merging and this will also require consideration. One important source of information in the decision-making process is the advice from numerical weather prediction (NWP) model output. The Meteorological Office currently uses the 15-level fine-mesh NWP model (Gadd 1985) for detailed advice over central and eastern parts of the North Atlantic, an area in which instant occlusion developments often take place. This paper examines the performance of the fine-mesh model in three cases of actual or potential instant occlusion development to assess whether realistic and helpful predictions were made. In addition, manual forecasting guidelines suggested in a previous paper are examined to see how useful they would have been in each case.

2. A review of instant occlusion processes

Anderson *et al.* (1969) described a merging process between a polar vortex and a front which produced a cloud pattern similar to that of a conventional occlusion. Where observation density was sufficient, it was noted that the rain band of the cold-air trough and the rain area associated with the frontal wave had also merged. The synoptic analysis placed a line of surface discontinuity near the rear edge of the polar vortex/trough cloud area and it is this feature which was referred to as the 'instant occlusion'. This model is similar to that used by Browning and Hill (1985) who proposed the principal airflows of such a system shown in Fig. 1. In both cases, the polar front remained the major baroclinic discontinuity. Fig. 1 also shows the frontal analysis which is normally applied in such situations along with the idealized 850 mb wet-bulb potential temperature (θ_w) field; the strong 850 mb θ_w frontal-zone gradient gives way to a much weaker gradient in the cold air.

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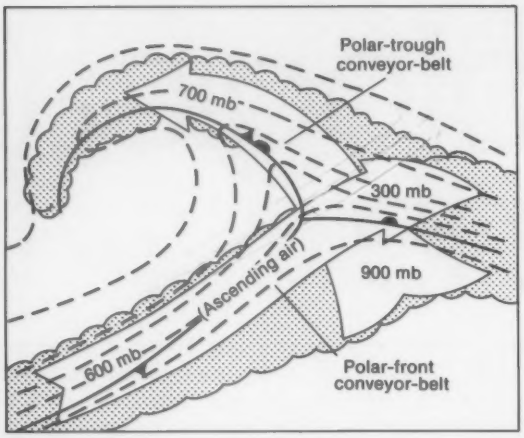


Figure 1. Airflows relative to the motion of the cloud band of the cold-air vortex in the systems described by Browning and Hill (1985). Fronts are shown conventionally. Pecked lines are idealized 850 mb wet-bulb potential temperature (θ_w) isopleths at one degree Celsius intervals. Stippling represents the main cloud areas.

By contrast, the studies of Locatelli *et al.* (1982) suggested a different analysis, where the cold-air trough was identified as a separate baroclinic disturbance. When merging occurred, the transition to cold air became associated with the trough line rather than the polar front. McGinnigle *et al.* (1988) investigated several instant occlusions of this second type and suggested the principal airflows and low-level thermal structure shown in Fig. 2. Fig. 2(a) is the 'conventional' instant occlusion analysis while Fig. 2(b) shows the alternative scheme which was proposed as a more realistic synoptic description.

It will be seen that Fig. 2 indicates a fundamentally different type of development from that described by Browning and Hill in Fig. 1. In the Browning and Hill model (which will be called the 'Type 1' instant occlusion in this paper) a polar-trough (cold) conveyor-belt flows from low levels beneath the polar front conveyor belt and produces the instant occlusion cloud band as it rises towards the forward side of the polar vortex; in Fig. 2 (Type 2 instant occlusion), a warm conveyor belt derived from a low-level shallow moist layer ahead of the polar trough feeds the instant occlusion cloud area. The existence of this shallow, moist layer is a consequence of the northward transportation of modified polar air ahead of the polar trough.

It is also important to observe that the cloud areas associated with the two models shown in Figs 1 and 2 are very different. The Type 1 development has a narrow belt of mainly convective cloud extending at approximately a right angle from the frontal zone and curving towards the cold vortex; infra-red imagery will normally show that this cloud is warmer (lower) towards the front and the edge of the polar-front conveyor-belt (jet stream) will often be clearly visible.

The Type 2 instant occlusion develops a distinctive hook of cloud as it merges; this hook forms by the

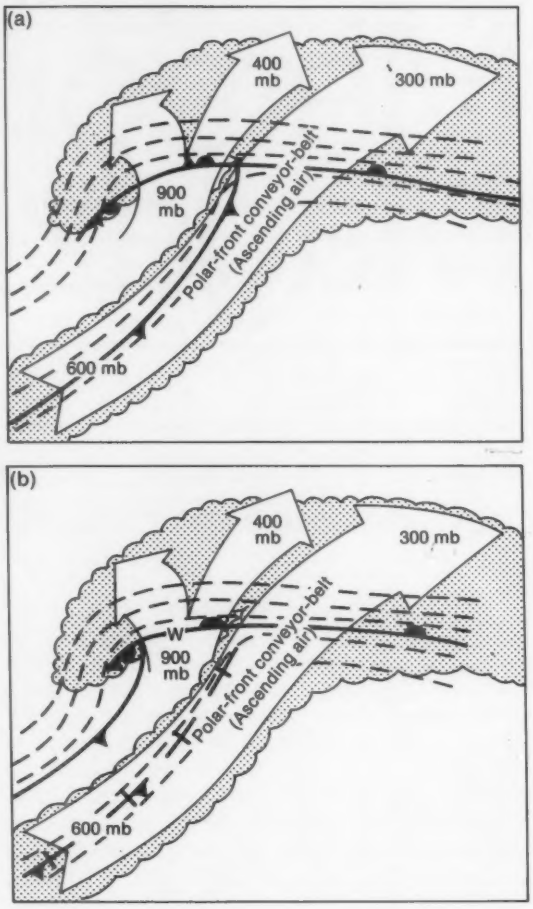


Figure 2. Airflows relative to the motion of the cloud band of the cold-air vortex, (a) 'conventional' and (b) 'alternative' analysis, in the systems described by McGinnigle *et al.* (1988). Fronts shown conventionally (bars indicate weakening). Pecked lines are idealized 850 mb wet-bulb potential temperature (θ_w) isopleths at one degree Celsius intervals. Stippling represents main cloud areas.

apparently rapid rotation of the comma-shaped part of the polar-trough cloud. In fact, this development is due to increasing positive vorticity advection, which results in marked ascent in the merging region, and imposes downward motion at the rear part of the hook, thus creating the illusion of sudden rotation. At the surface, increasing advection of moist, warm, low-level air on the forward side of the polar trough progressively diminishes the thermal contrast across the cold front and so weakens it.

In the Type 2 model, considerable potential instability is generated by the existence of cold dry air at middle and upper levels overlaying warm, moist air at low levels and this is released when merging occurs. By contrast, the Type 1 model generates little potential instability and this marked difference in the models is a significant factor which will assist the forecaster to make the correct type identification.

In comparing both types of instant occlusion events, McGinnigle *et al.* (1988) suggested that, where interaction takes place, polar troughs which have little baroclinicity associated with them are likely to develop into Type 1 instant occlusions, whereas troughs which possess baroclinicity before interaction tend to form Type 2 instant occlusions; it was also observed that, of the two types, the latter appeared to be the more common feature in the North Atlantic.

In data-sparse areas, it will often be difficult to positively establish the degree of baroclinicity possessed by a polar trough. However, Weldon (1979) has suggested that an indication of frontogenesis (and therefore increasing baroclinicity) may be inferred from infra-red satellite imagery. If the cold air feature contained dense, layered cloud (sometimes leaf-shaped), this can be an indicator of associated baroclinicity; by contrast, the comma-shaped cloud consisting mainly of convective cells, characteristic of a positive vorticity advection (PVA) maximum, would suggest that little baroclinicity was present.

This leaf-shaped cloud mass (the 'baroclinic leaf' or 'cloud-head') is a well-accepted precursor of cyclogenesis. It has been observed that some explosive cyclogenesis situations have been preceded by a large 'cloud-head' formation (Böttger *et al.* 1975, Monk and Bader 1988). Reed and Blier (1986) showed that some comma clouds contain large mesoscale convective elements and Young (1988) has observed that the leaf-shaped cloud area associated with Type 2 instant occlusion developments can initially consist of several distinct mesoscale convective elements, before becoming the extensive layered structure seen to precede explosive cyclogenesis.

3. The case-studies

In the case-studies which follow, all the satellite imagery presented is from NOAA polar-orbiting satellites; these images have the best resolution to show the details of the developments. However, much use was also made of Meteosat geostationary imagery and especially of fast movie-loop sequences showing infra-red images (D2 frame) spaced one hour apart. These were used to determine the time at which merging took place and to observe the details of the instant occlusion process at that time.

NWP analysis and forecast fields from the fine-mesh model were available as hard copy from T+0 hours to T+36 hours in 6-hour time-steps but use was also made of output in 3-hour time-steps, available only as soft copy. This was viewed on a high-resolution colour graphics VDU and could be displayed as a movie loop through the time series of the model run; this was useful in establishing the time and details of instant occlusion merging, as predicted by the model.

The following analysis and forecast fields were used to examine and assess the performance of the model runs in each case:

Surface isobars and precipitation (dynamic and convective)
850 mb wet-bulb potential temperature (θ_w)
1000–500 mb thickness and 500 mb contours
250 mb wind speed and direction
Maximum wind isotachs
Vertical motion and thermal advection (850–500 mb layer)
Medium- and high-level convective depth
Medium and low cloud
500–850 mb θ_w difference ($\Delta\theta_w$)

In this paper, the model output charts presented concentrate on the first two items from the list above since this part of the output will normally be routinely available to the forecaster. Surface isobars/precipitation is used as the base chart and the 850 mb θ_w contours are added as appropriate. The vertical motion/thermal advection fields are also shown to explain the model developments. Significant features of the other relevant fields are described in the text. The model runs chosen for detailed examination are those whose Data Time (DT) precedes the instant occlusion event by 12–18 hours; subsequently, two earlier model runs are also briefly appraised.

The paper also intends to test the manual forecasting guidelines proposed by McGinnigle *et al.* (1988) in respect of their usefulness in the pre-merging stage. These guidelines were formulated on the basis of the study of Type 2 instant occlusions only but it is intended to test them against all the cases presented in this paper, which includes a Type 1 development. For this purpose, they will be slightly adapted.

The relevant guidelines were:

'An instant occlusion ...(of Type 2)... may form if all the criteria (i)–(iii) below are satisfied:

(i) A cold-air cloud cluster, which may be leaf-shaped, contains dense layered cloud.

(ii) Surface reports or numerical model diagnostics (e.g. 850 mb θ_w) show that a thermal gradient is associated with this cloud.

(iii) The cloud is embedded in a strong upper flow that will carry it to within 350 n mile of the polar front (Marshall 1982).'

The guidelines will be adapted to apply to potential Type 1 instant occlusion cases as follows:

If examination of a polar trough produces negative answers to (i) and (ii) above, it will be concluded that the trough has formed largely as a response to PVA, and that there is no significant baroclinicity involved. Then, if the answer to question (iii) is affirmative, the formation or otherwise of a Type 1 instant occlusion will test whether this adaptation of the manual forecasting guidelines has any validity. Since Marshall's criterion refers to the critical distance between a 'PVA' and a 'cold front', it is assumed here that the measurement should be from a central point within the 'head' of the comma cloud to the edge of the frontal band where the wave inflection is observed.

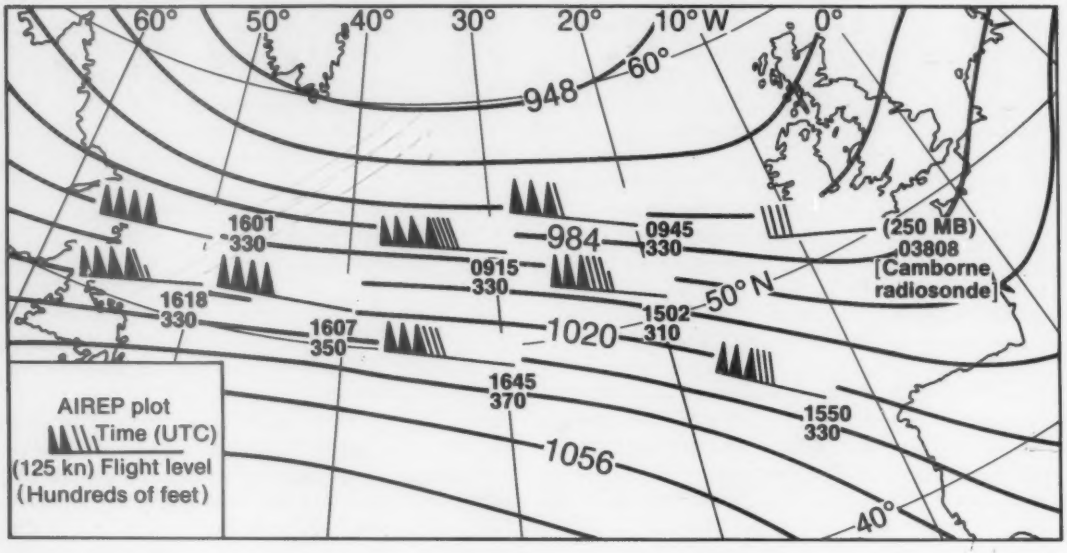


Figure 3. Upper-air pattern (dam) at 250 mb at 1200 UTC on 24 February 1989 with plotted aircraft reports 0915–1645 UTC. Wind arrows are shown traditionally.

3.1 24 February 1989

3.1.1 Synoptic events

The broad-scale situation over the North Atlantic around this date was characterized by an upper jet-stream of exceptional strength. Fig. 3 shows the wind regime which existed at 250 mb at 1200 UTC on 24 February 1989; the strongest reported wind was 240 kn and there were a number of aircraft reports with winds in excess of 200 kn. Infra-red imagery across the North Atlantic showed a very wide band of cloud (at least 5 degrees of latitude) associated with this broad baroclinic zone and surface observations suggested that the main surface frontal discontinuity was located towards the southern boundary of this cloud band (Figs 4(a) and 5(a)).

By 0000 UTC on 24 February, a polar low and trough south of Greenland was observed to be moving quickly east-south-east; in addition, a second weaker low was analysed in the cold air around 55° N, 35° W, on the evidence of ship observations in that area. The satellite imagery around this time clearly marked the main low and trough but, at this stage, there was little cloud evidence for the second low. The NOAA satellite imagery at 0450 UTC on 24 February (Fig. 5(a)) shows the complexity of these features. Near the southern end of the trough cloud, around 37° W, the configuration of the jet-stream cirrus suggested that there were two minor baroclinic waves on the front and these were included in the surface analyses for both 0000 and 0600 UTC on 24 February 1989. The model initialization fields at 0000 UTC agreed with the various elements of the analysis described above. Fig. 6(a) shows the T+0

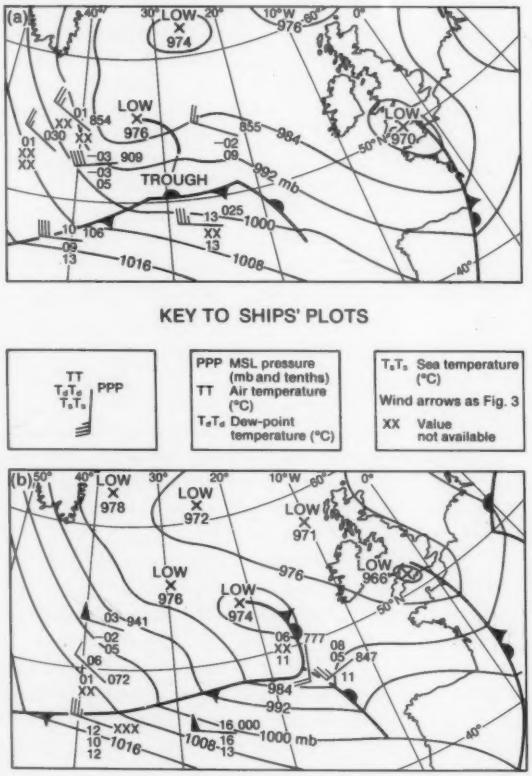


Figure 4. Surface synoptic analyses on 24 February 1989 for (a) 1200 and (b) 1800 UTC. Surface fronts are shown conventionally. Plotted observations are ship reports, with traditional wind arrows.

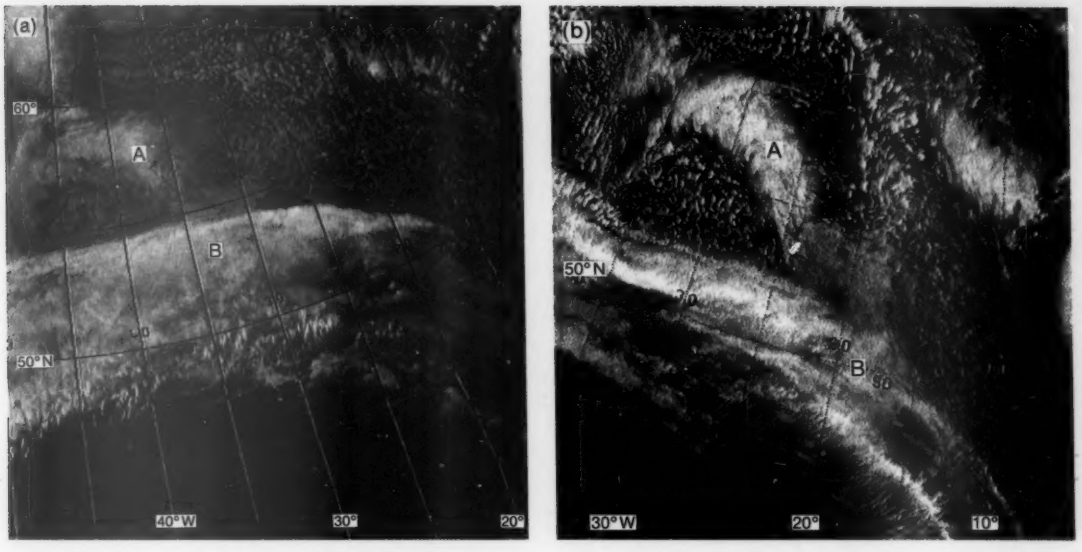


Figure 5. NOAA infra-red satellite imagery for 24 February 1989, (a) 0450 and (b) 1411 UTC. All times are equator crossing times. Cloud area labelled A is the polar trough cloud and B is the frontal band.

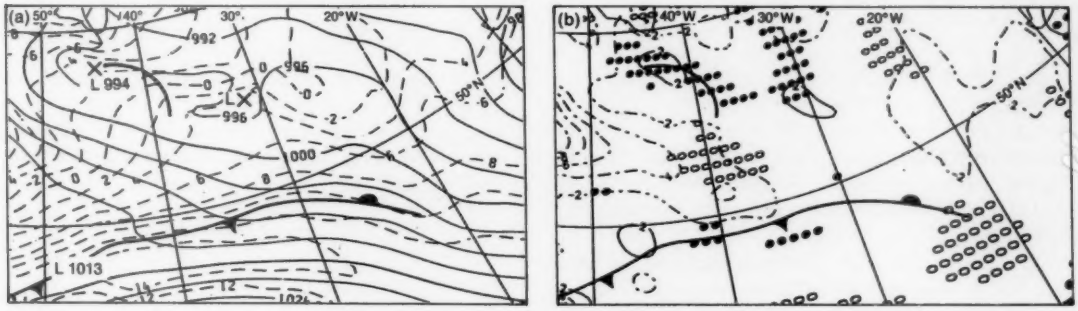


Figure 6. Fine-mesh model analyses for Data Time 0000 UTC on 24 February 1989. (a) Surface pressure pattern (solid contours) and 850 mb θ_w field (°C), and (b) diagnostic fields — thermal advection (dashed contours — cooling, full contours — warming, and vertical velocity (open symbols — descending, closed symbols — ascending). Thermal advection/vertical velocity is average of 850, 700 and 500 mb fields, as Fig. 7(b).

surface pressure and 850 mb θ_w fields, with the cold lows and the frontal zone realistically positioned, and the coincident diagnostic chart (Fig. 6(b)) indicated significant uplift associated with the forward side of the surface lows and somewhat lesser values near the front. Both the 850 mb θ_w field and the diagnostic chart suggest a Type 1 model and this was confirmed by the $\Delta\theta_w$ distribution, which showed no potential instability near the waves.

Following very rapid east-south-east movement, cloud developed ahead of the forward cold low, and the associated surface trough and the wave merged into an instant occlusion. The original PVA trough cloud further west became progressively more detached from the forward feature. Fig. 5(b) shows the time at which the forward trough cloud was developing quickly near the frontal cloud band and a study of the Meteosat imagery movie sequences suggested that merging took place around 1600 UTC. During the following hours, the two areas of trough/instant occlusion cloud continued to become more separate, indicating that two enhanced areas of PVA had developed on the cold side of the very strong jet. After the instant occlusion merging had taken place, the more easterly of the lows moved quickly east-south-east and deepened further near southern England, where the central pressure fell to 950 mb for a time.

Figs 4(a) and 4(b) show the surface analyses for 1200 and 1800 UTC on 24 February. At both times, the polar trough/instant occlusion is placed near the rear boundary of the polar trough cloud. At 1800 UTC, the ship report at 50.3° N, 16.2° W helped to place the recently formed instant occlusion precisely; this ship reported a rapid pressure fall (7.6 mb) over the period

1500–1800 UTC and reflected the movement of the forward cold low as well as the approach of the instant occlusion troughing. The existence of convective cells immediately behind the instant occlusion (partially shielded by upper cloud) coupled with warmer (lower) instant occlusion cloud tops to the north of the wave tip suggested that this case was a Type 1 instant occlusion, as defined earlier in this paper.

3.1.2 Fine-mesh model run DT 0000 on 24 February 1989

Fig. 7 shows output from the above model run, whose initialization fields have already been discussed in the previous section, covering the period around which the instant occlusion formed. Figs 7(a), 7(c) and 7(e) show the surface isobars and precipitation distributions which were predicted by this model run; the 850 mb θ_w fields have been added in the area around the trough. The concurrent thermal advection/vertical velocity diagnostic forecast fields are shown alongside.

In the forecast for 1200 UTC on 24 February (T+12 hours, Fig. 7(a)), the 850 mb θ_w gradients (also the 1000–500 mb thickness gradients, not shown) in the vicinity of the forward trough were relatively slack in comparison with those in the cold-front region towards the western wave. Higher 850 mb θ_w values marked the line of the trough and there was a largely uniform decrease in these values in the following cold air. The precipitation distributions showed an area of dynamic rain associated with the cold low/trough but only a few rain symbols near the wave; at this stage, there was no evidence to suggest instant occlusion formation and this is in accordance with the actual surface analysis at 1200 UTC on 24 February.

The thermal advection/vertical velocity fields (Fig. 7(b)) showed an extensive area of ascent ahead of the polar trough, much of which was not collocated with an area of warm advection between 48 and 55° N. Cold advection was shown behind the trough but there was further significant ascent in the cold air ahead of the polar low and trough further west. Convective-cloud-depth forecasts indicated extensive deep convection in the cold air and around the cold low; however the $\Delta\theta_w$ fields suggested that potential instability would be present only in the immediate vicinity of the cold low ($\Delta\theta_w \approx 0$ °C).

Figs 7(c) and 7(d) show the model predictions 6 hours later at 1800 UTC. Some buckling in the thermal fields (850 mb θ_w and 1000–500 mb thickness) was evident and the area of dynamic rain had extended towards the wave tip; however, no dynamic rain was predicted in the area of the wave; the area of uplift was strengthened and extended south-east with the thermal advection values largely unchanged. At this stage, the model did not suggest that the instant occlusion process had taken place (this actually occurred at 1600 UTC).

The T+24 hour forecast frames (Verification Time (VT) 0000 on 25 February, Figs 7(e) and 7(f)) predicted that considerable development would take place during the preceding 6-hour period and produced what proved to be a generally realistic low-pressure complex to the west of Ireland. The rain area now extended along the trough to the frontal wave suggesting that an instant occlusion had been formed (this had occurred before 2100 UTC). There was a large area of ascent near the instant occlusion, and the warm advection showed some increase, though still remained below 4 °C/6 hours. Convection was forecast to become deeper and more extensive in the cold air; as before, potential instability was forecast only in the area of the cold low. This evidence suggested that the instant occlusion would be a Type 1.

A brief examination of the two immediately previous model runs (DT 0000 and 1200 UTC on 23 February) showed that both had also predicted the formation of a Type 1 instant occlusion. However, there were significant differences in timing and development. The earlier run was far too progressive and the following run developed too much upper trough extension in the cold air, leading to a considerable overdevelopment of the wave, trough and cold low.

3.1.3 Discussion

This chosen model run (DT 0000 UTC on 24 February) presented a realistic sequence of events in many respects. System positioning was good and the development of the low west of Ireland was well handled. The forecast frames gave an indication that the trough and wave would merge and, on the evidence presented by the diagnostic fields and the instability predictions, that this would be a Type 1 instant occlusion. However the timing of the development was in error by several hours; merging did not occur until between 1800 and 2100 UTC (actual event 1600 UTC). Positioning of the instant occlusion was accurate. Dynamic rain was perhaps under-forecast but this cannot be positively established due to the paucity of actual reports in the area. The two previous runs were less successful but still predicted instant occlusion merging.

With regard to the test of the manual forecasting guidelines, at 0000 UTC on 24 February, attention would have been directed towards the major polar low and trough south of Greenland since there was little evidence of any forward development at this time. Applying the guidelines to this area, the appearance and configuration of the trough cloud would not have suggested pre-existing baroclinicity (negative replies to questions (i) and (ii)) and therefore indicated that any instant occlusion formation would be a Type 1. The distance from the centre of the comma head (north of the surface vortex) south-eastwards to the frontal cloud was around 350 n mile and the imagery sequence and upper-wind flow inferred that this spacing would not change much. Thus, strict application of the guidelines would have suggested that Type 1 instant occlusion formation was marginally possible; in fact, this part of

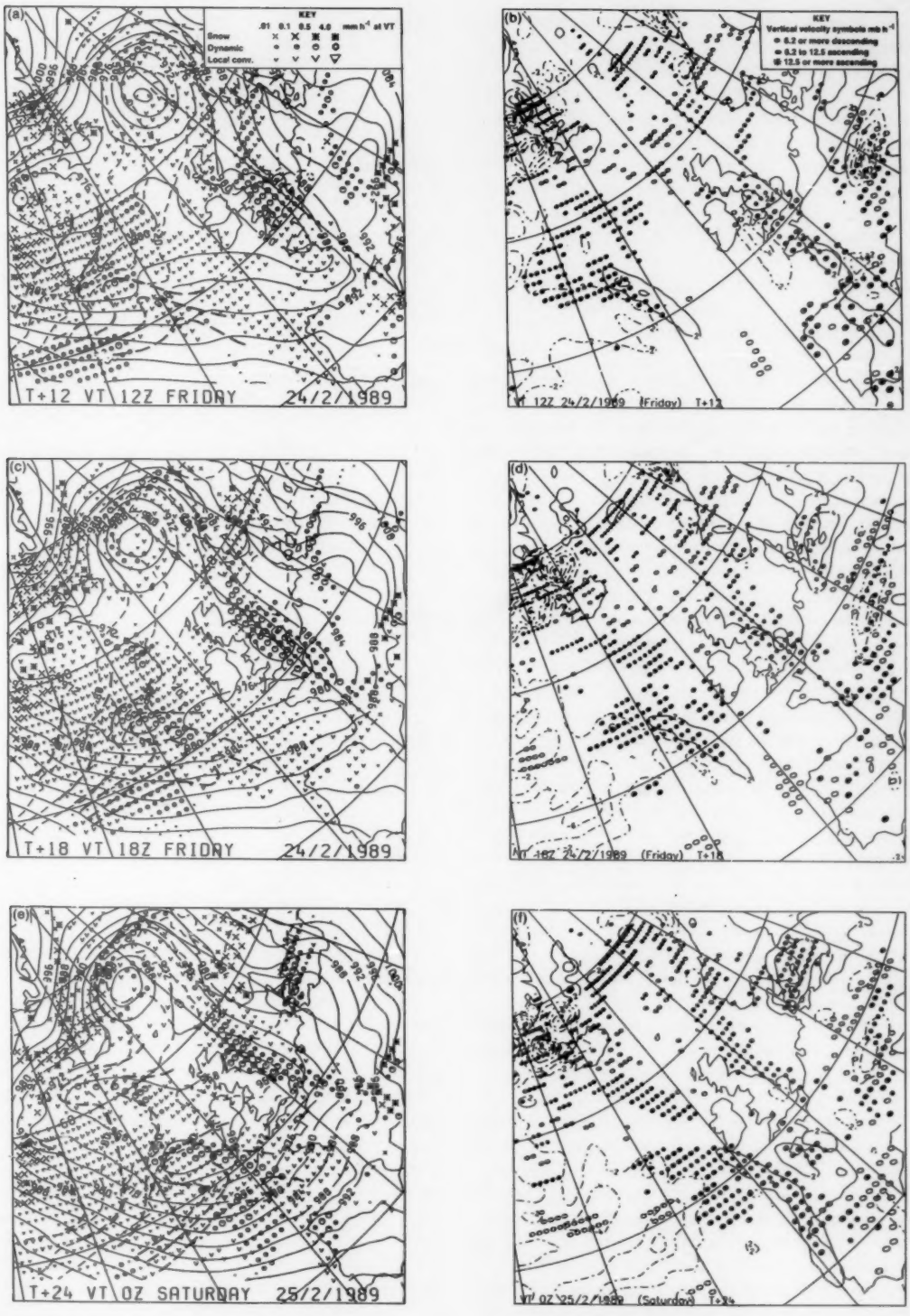


Figure 7. Fine-mesh model predictions Data Time 0000 UTC on 24/25 February 1989. Rainfall rate and m.s.l. pressure: (a) Verification Time (VT) 1200 UTC on 24 February, (c) VT 1800 UTC on 24 February, and (e) VT 0000 UTC on 25 February. Model diagnostics: (b) VT 1200 UTC on 24 February, (d) VT 1800 UTC on 24 February, and (f) VT 0000 UTC on 25 February.

the development did not subsequently form an instant occlusion because of the formation of a new downstream PVA maximum. A later application of the guidelines (e.g. 0600 UTC) to the forward development would have produced a spacing of around 200 n mile, suggesting that the instant occlusion process should already have taken place; however it is reasoned in this case that this instant occlusion formation was a response to *in situ* developmental factors for which the guidelines are not designed.

3.2 15 March 1989

3.2.1 Synoptic events

Fig. 8(a) shows the actual surface analysis at 1200 UTC on 14 March 1989, at which time a well-established polar trough had approached the polar front. A baroclinic wave had been identified on the front as shown and the area containing the polar low/trough and the wave was situated on the forward side of a confluent upper trough. Infra-red imagery at 1445 UTC (Fig. 9(a)) showed that these features were separate at this time; the polar trough was comma-shaped but, in its northern part, there was a large area of layer cloud, with some embedded convection, and this streamed forward in the suggestion of a classic 'leaf' shape.

As the upper trough relaxed forward, the frontal wave and the polar trough moved east-north-east and merged to form an instant occlusion around 1200 UTC on 15 March (Fig. 8(b)). This was identified from examination of the movie-loop sequence showing hourly Meteosat images as described previously. Between 1100 and 1200 UTC there was a sudden thickening and increase of cloud in the area north-west of the wave tip and, simultaneously, the 'tail' of the comma cloud weakened, giving the illusion that there had been a sudden rotation of the cloud mass. The satellite imagery at 1435 UTC (Fig. 9(b)) shows the post-merged situation; it will be seen that merging took place well ahead of the line of the surface polar trough, which can be seen as a somewhat degenerated comma-shape in the cold air.

It is also noted that there was no convective cloud on the cold side of the front and that there was little change in surface temperature or dew-point reported across the front at this time; this had been a feature of the surface analyses of the previous 24 hours, all of which showed that the really cold air was located behind the polar trough line. Convective cloud in this cold air mass was limited by marked downward vertical motion to the rear of the confluent upper trough.

The T+0 hour model initialization fields, DT 0000 UTC on 15 March, confirm the details of the analysis. The surface analysis (Fig. 10(a)) shows the front and the wave correctly positioned and the 850 mb θ_w field indicates a double thermal structure at the waving front and to the north-west of the cold low while the diagnostic chart (Fig. 10(b)) shows a large area of

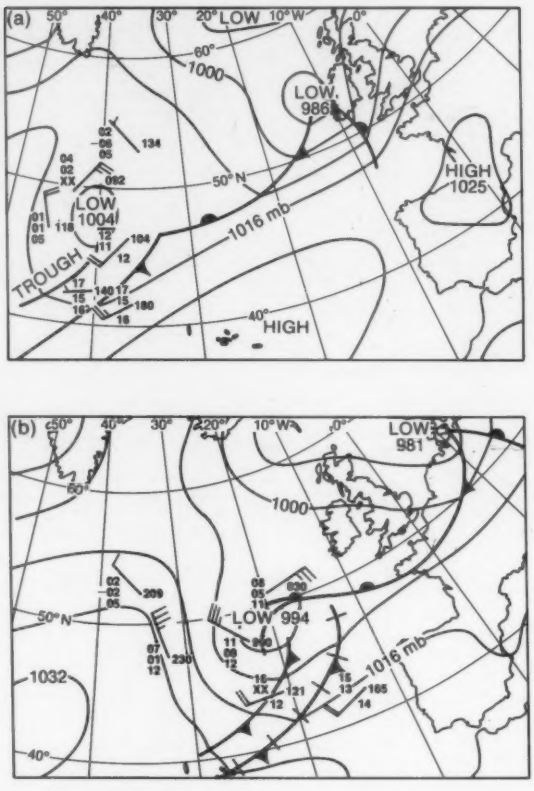


Figure 8. As Fig. 4 but for (a) 1200 UTC on 14 March 1989 and (b) 1200 UTC on 15 March 1989. Bars across forward cold front indicate weakening.

downward motion coupled with some cold advection between front and trough; this is associated with an indication of potential instability in this area from the $\Delta\theta_w$ field ($\Delta\theta_w$ values <1 °C).

The evidence above establishes that this was a Type 2 instant occlusion development as defined earlier. During the following 12 hours the surface low elongated eastwards and a new surface low formed on the triple point (wave tip). This new low moved eastwards across southern England and became established as the main low by 1200 UTC on 16 March, at which time it had deepened to 990 mb and was beginning to occlude conventionally; the original polar low became absorbed in its circulation and eventually lost its identity. This sequence of events has been noted to be characteristic of the behaviour of the Type 2 instant occlusion development.

3.2.2 Fine-mesh model run DT 0000 UTC on 15 March 1989

Fig. 11 shows the predictions from the above model run during the period 0600–1800 UTC (T+6 to T+18 hours). The distribution of dynamic rain (and forecast

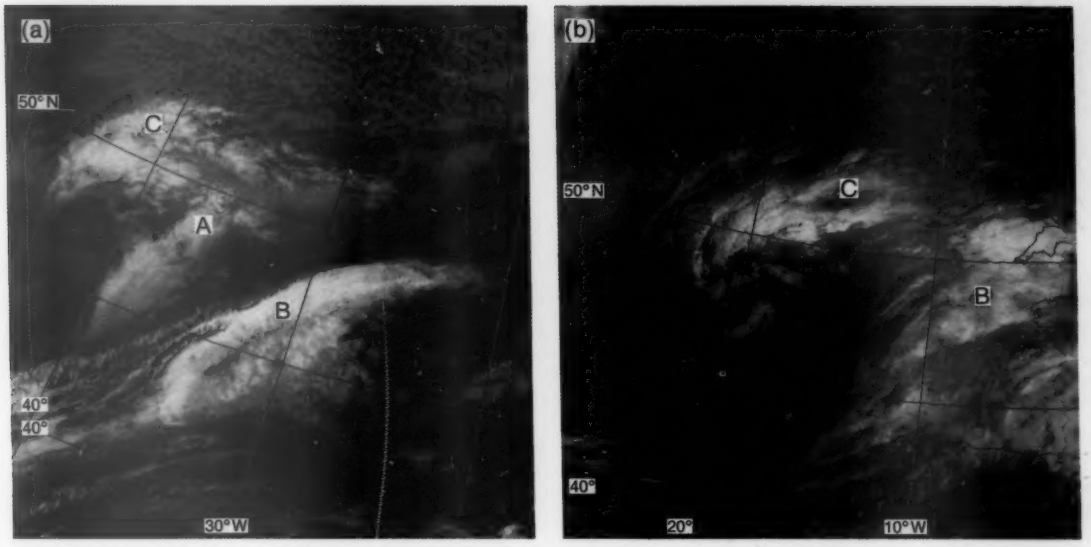


Figure 9. As Fig. 5 but for (a) 1431 UTC on 14 March 1989, and (b) 1421 UTC on 15 March 1989. C is the leaf-shaped cloud referred to in the text.

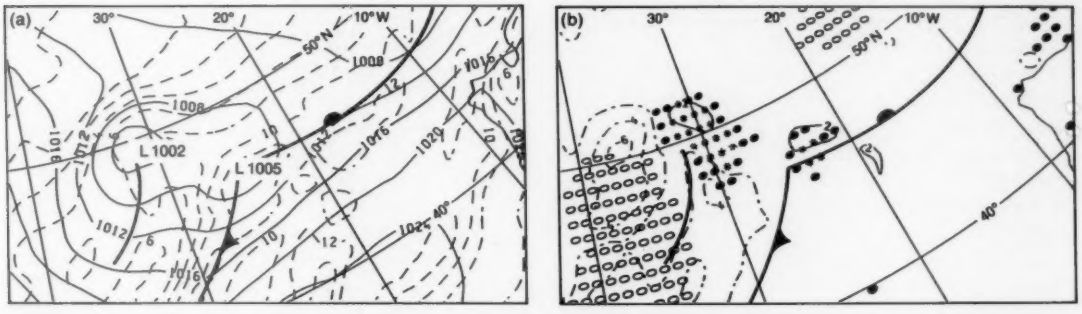


Figure 10. As Fig. 6 but for DT 0000 UTC on 15 March 1989, see key in Fig. 7.

cloud) at 0600 UTC showed the wave and trough as separate features, with some shower activity between. The 850 mb θ_w field indicated that the air behind the cold front was relatively warm (850 mb $\theta_w = 8$–10 °C) and showed significant θ_w gradients on both front and polar trough; the polar trough gradient also extended eastwards near 50° N. Extensive shower activity was forecast in the cold air further north. The diagnostic fields (Fig. 11(b)) indicated that most of the uplift was due to PVA but also with some warm advection shown on the forward side of the frontal wave. The $\Delta\theta_w$ forecast fields continued to show that the area near the wave tip would be highly potentially unstable ($\Delta\theta_w = -1$ °C); potential instability would also be present along the polar trough and in the zone between the polar low and the wave.

Figs 11(c) and 11(d) show the situation 6 hours later, around the time of instant occlusion formation. The areas of dynamic rain have merged and the wave has deepened a little. The separate thermal gradients associated with front and trough have been maintained and there has been a concentration of the gradient along 50° N. However the diagnostic chart (Fig. 11(d)) still shows a gap in the uplift between trough and wave. Considerable potential instability was again shown near the wave, with a tongue of $\Delta\theta_w \leq 1$ °C values extending west-north-west to the polar-low area.

Finally, the T+18 hour forecast (Figs 11(e) and 11(f)), showed the cold low to be degenerating to a trough, and forecast a line of dynamic rain along the line of the instant occlusion; thermal gradients are maintained as before and a band of strong uplift has been generated

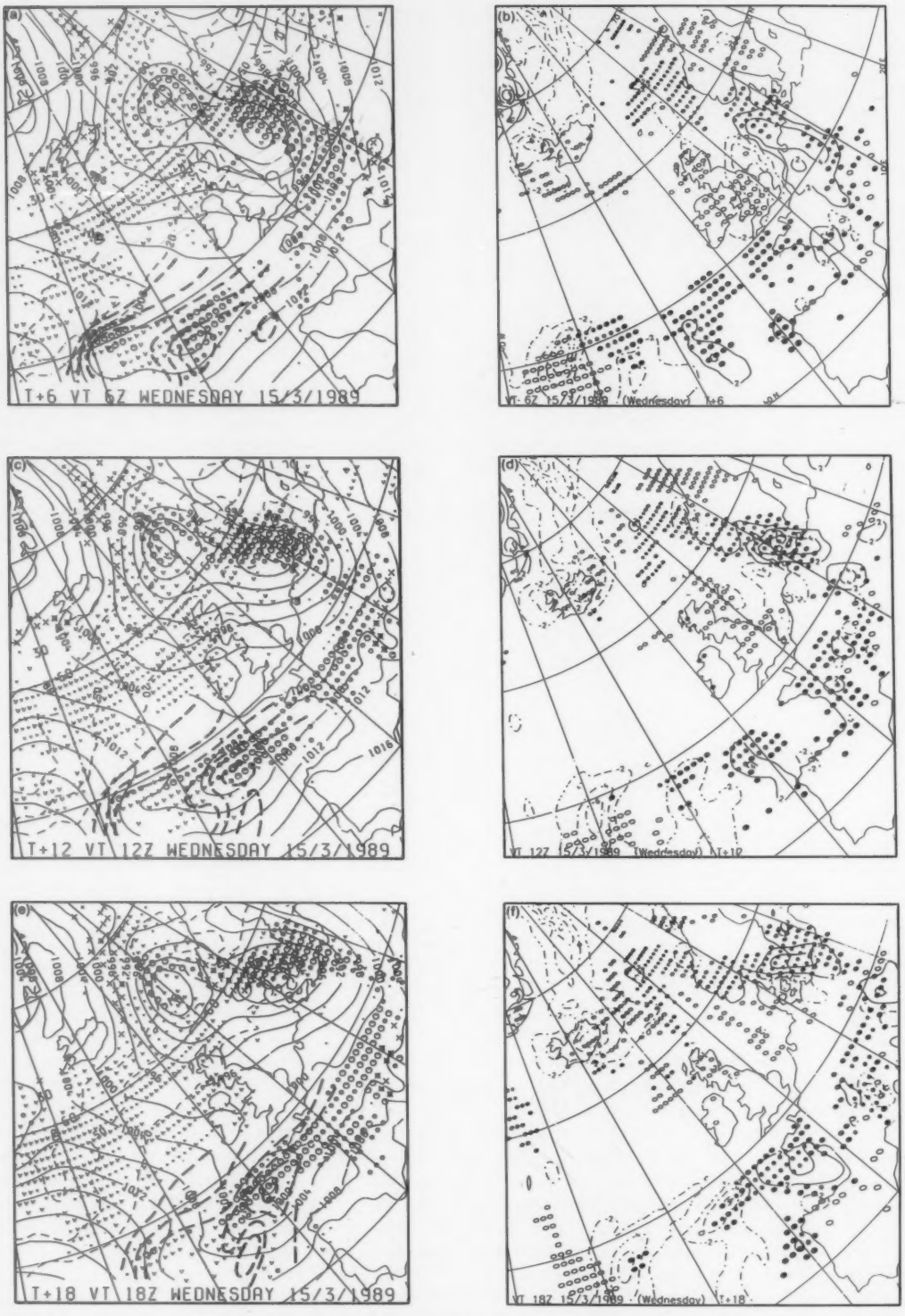


Figure 11. As Fig. 7 but for Data Time 0000 UTC on 15 March 1989. Rainfall rate and m.s.l. pressure: (a) Verification Time (VT) 0600 UTC on 15 March, (c) VT 1200 UTC on 15 March, and (e) VT 1800 on 15 March. Model diagnostics: (b) VT 0600 UTC on 15 March, (d) VT 1200 UTC on 15 March, and (f) VT 1800 UTC on 15 March.

along the instant occlusion and especially near the low. Significant potential instability is again forecast. This model sequences strongly suggested that a Type 2 instant occlusion had formed.

The two previous model runs (DT 0000 and 1200 UTC on 14 March) produced realistic sequences of Type 2 instant occlusion development. However, there were positional errors, especially with the earlier run which was far too progressive.

3.2.3 Discussion

This model run captured the essential details of a Type 2 instant occlusion development; the thermal gradients indicated that there was baroclinicity on the polar trough as well as the front and the existence of a shallow moist zone (SMZ) behind the cold front was well predicted. The forecast of significant potential instability in the merging zone was yet another feature of significance, since the release of potential instability has been recognized as an important mechanism in Type 2 instant occlusion development. Indeed it is noted that this distribution of potential instability is an important precursor of this type of development; this is completely different from the potential instability distribution associated with a Type 1 instant occlusion case, as indicated in the previous case-study.

The merging process was well shown by the vertical motion/thermal advection fields, developing a large area of strong ascent in the appropriate place, though possibly a few hours later than the actual event was observed to take place. However, it is important to note that careful examination of the precipitation forecasts alone would have given a good indication that Type 2 instant occlusion development was forecast to occur and this would be confirmed by consideration of the thermal fields. The model was less successful in predicting the eastward development of the low and with the degeneration of the cold low (both too quick). The previous model runs confirmed Type 2 instant occlusion development but had serious positional errors.

The application of the manual forecasting guidelines should have led to the conclusion that this was a potential Type 2 occlusion case. This would have been suggested by the imagery in the earlier stages and ship reports would have confirmed the development of a SMZ behind the cold front as the polar trough came closer. The upper-wind patterns at 1200 UTC on 14 March and 12 hours later at 0000 UTC (the chosen model DT) would have suggested that PVA and wave cloud should converge, probably reaching the critical spacing during 1200–1800 UTC on 15 March. This would have given a realistic prediction of events. Examination of the imagery sequences revealed that the wave and the polar feature converged very slowly during the period before the instant occlusion had formed. Fig. 9(a) suggests that the 'baroclinic leaf' and the wave cloud area were separated by around 550 n mile at that time and Fig. 9(b) shows a spacing of around 350 n mile. This may suggest that merging had taken place (at 1200 UTC) when the spacing was slightly larger than the specified 350 n mile criterion but, in view of measurement uncertainties, it would be inappropriate to draw any conclusion of positive model error.

3.3 1/2 May 1989

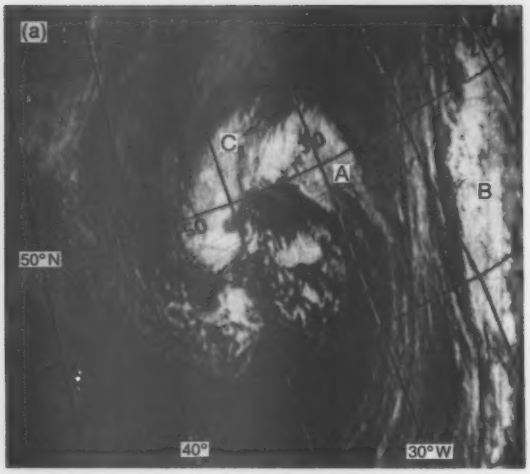
3.3.1 Synoptic events

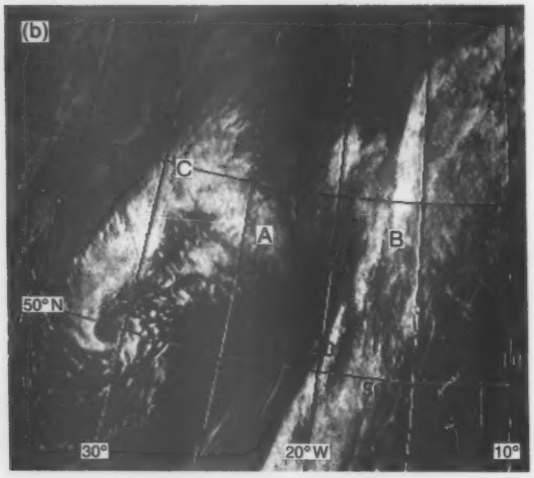
This was a case where the interaction between a polar trough and the polar front appeared to be at a critical but relatively unchanging stage for a period of 24 hours. Although instant occlusion merging did not occur, the imagery and actual analyses for the period suggested that linkage was almost achieved. As such, this case is an interesting test of instant occlusion merging criteria, for both model performance and manual guidelines.

The polar low/trough was located on the forward side of a sharp upper trough which became more confluent as it moved east across the Atlantic, bringing the surface trough closer to a baroclinic wave which had formed on the front. Positive signs of merging were observed to occur around 1600–1700 UTC, with the polar trough cloud apparently rotating quickly towards the wave tip; however this merging did not occur and the 'almost merged' situation proceeded virtually unchanged as the features ran north-east towards the Norwegian Sea. Fig. 12 shows a series of infra-red images, covering a 32-hour period and including the time when merging seemed to be commencing (Fig. 12(b)). At this time, cloud was increasing rapidly to the west of the wave and this appeared to reach a peak around 1600–1700 UTC — this being established by a study of the movie-loop of Meteosat hourly infra-red images.

Imagery during the next 24 hours indicated little change in the cloud pattern as the development ran north-north-east towards the Norwegian Sea. Fig. 12(c) shows the imagery almost at the end of this period. Like the previous case, it is noted that the comma-shaped polar trough cloud has a forward element of mainly layer cloud streaming forward in the south-westerly upper flow (indicating a degree of baroclinicity on the trough) and that deep convective cloud is located only to the rear of the polar trough line. These cloud configurations would suggest that any instant occlusion development would have been a Type 2 and this was confirmed by examination of the T+0 model fields at DT 0000 UTC on 1 May (the chosen model run for this case). The relevant fields (not shown) were similar to the previous Type 2 case; the 850 mb θ_w had a double structure (albeit rather weak near the trough), vertical motion was downwards in the SMZ zone and potential instability was also present in the zone.

Figs 13(a) and 13(b) show the actual surface analyses during the period when it seemed that merging was about to occur. At 1200 UTC on 1 May 1989, the polar vortex and trough had approached the waving cold front. The two features were very clearly separate on all





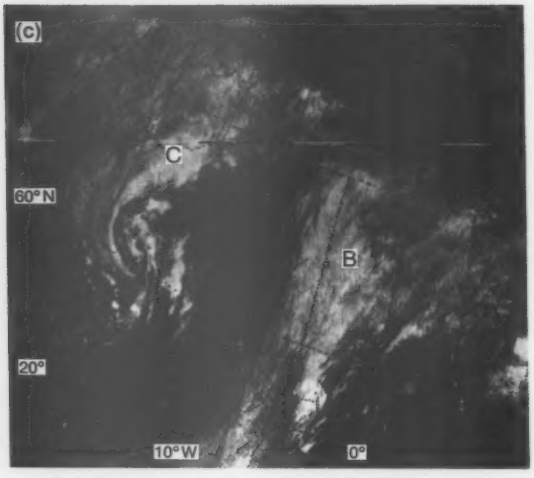


Figure 12. As Figs 5 and 9 but for 1/2 May 1989 at (a) 0522 UTC on 1 May, (b) 1444 UTC on 1 May, and (c) 1251 UTC on 2 May.

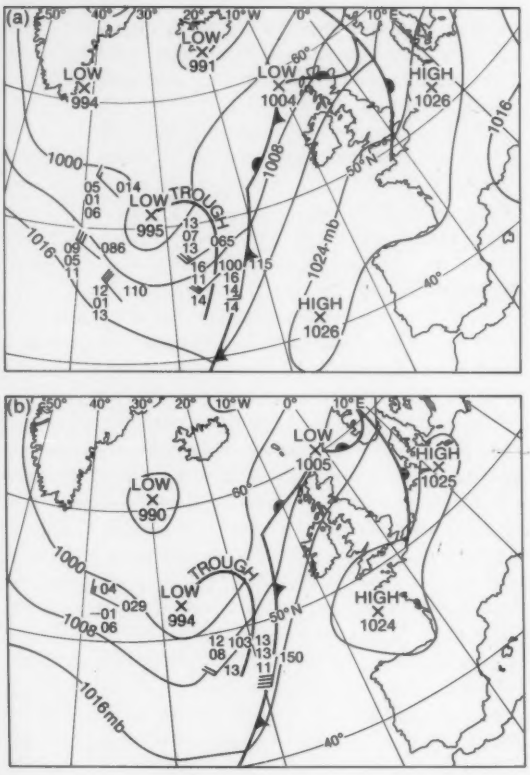


Figure 13. As Fig. 4 but for 1 May 1989 at (a) 1200 UTC and (b) 1800 UTC.

the imagery at that time and ship reports of active showers helped to place the trough line on the surface chart. Examination of all ship reports around this time suggested that dew-points fell from 14 to 11 °C across the cold front and then decreased by another 2 or 3 °C across the trough; further surface troughing was evident south of the polar low as a line of enhanced convection on the imagery, and the air became colder in the north-westerly airstream which followed, with a dew-point of −1 °C reported at Ocean Weather Station 'C'. This identified a SMZ between the front and the polar trough.

The 1800 UTC surface analysis showed the polar low had moved north-east, parallel to the movement of the wave; the trough had been rotated north-east and was placed largely on the evidence of satellite imagery, since surface reports were very sparse. As there was no direct evidence to suggest that frontogenesis was taking place between the SMZ and the colder air to the north of the wave, it was not appropriate to place a line of surface discontinuity there. Such a line would have been placed between polar low and wave tip, along the strong 850 mb θ_w gradient, and would have marked the beginning of a Type 2 instant occlusion development.

As can be seen from Fig. 12(c), the polar trough subsequently degenerated and it became increasingly

difficult to locate the line of the trough on surface analyses. Later surface analyses placed a single trough line rotating around the polar low, well away from the frontal wave.

3.3.2 Fine-mesh model run DT 0000 UTC on 1 May 1989

Figs 14(a) and 14(b) show the model predictions for 1200 UTC on 1 May (T+12 hours), around 3 hours before the first indications of actual merging were observed. The surface isobars and precipitation forecast showed separate areas of dynamic rain associated with the trough and wave with a scattering of showers and dynamic rain symbols between them. The 850 mb θ_w field showed indications of a double thermal gradient structure (weak near the trough) and the diagnostic chart gave some support, with warm advection indicated at both wave and trough (again, weak at the trough). The strong 850 mb θ_w gradient extended from the wave tip south-westwards towards the cold low indicating the northern boundary of a SMZ; however, this gradient decreased markedly before it reached the area of the cold low. The $\Delta\theta_w$ field indicated that potential instability would extend along the line of the incipient link and in the SMZ.

Figs 14(c) and 14(d) show the forecast situation 6 hours later at 1800 UTC on 1 May. There was increased spacing between wave and trough and the dynamic rain between the systems had generally decreased although there was a westward extension of rain around 58° N. The strong 850 mb θ_w gradient was maintained near the wave but had moved further away from the polar trough. Uplift had generally diminished. The $\Delta\theta_w$ field showed that two separate areas of potential instability had developed from the single elongated area shown 6 hours earlier. Examination of the 1500 UTC forecasts revealed that there had been little change in the situation during the period 1200 to 1500 UTC; the degenerations noted at 1800 UTC had occurred between 1500 and 1800 UTC.

The T+24 forecasts (Figs 14(e) and 14(f)) maintained the spacing between trough and wave and indicated some precipitation development north-north-eastwards, with uplift (mainly PVA-generated) extending towards Iceland; there were increased rain/showers in this area. Merging with the wave tip further east was not suggested. Subsequently, the model forecasts to 1200 UTC on 2 May (T+36 hours) showed the polar low/trough and the frontal wave becoming well-separated features as they moved north-east to the Norwegian Sea, with no further signs of positive interaction.

Examination of the two previous runs (DT 0000 and 1200 UTC on 30 April) revealed a divergence of opinion. Both runs suggested a potential Type 2 situation and developed strong 850 mb θ_w gradients from wave to cold low, unlike the subsequent run already examined. The earlier of the two runs indicated a possible merging; the subsequent run was less enthusiastic. Both runs positioned the features too far east; this appeared to be due to an error in broad-scale development (too little trough extension) which caused too much upper flow to be maintained over the cold low.

3.3.3 Discussion

The chosen model run (DT 0000 UTC on 1 May) successfully indicated that an instant occlusion would not be formed. Neither precipitation or forecast cloud distributions suggested that this would occur, although the T+12 (and T+15) hour frames showed some development in the zone between trough and wave; subsequent frames correctly indicated precipitation/cloud degeneration in the merging zone. The slackening of the 850 mb θ_w gradient towards the cold low is seen as significant; this showed the northern boundary of the SMZ but the gradient was not maintained from the wave tip to the polar low/trough as shown in the previous (Type 2) case-study. Since this strong 850 mb θ_w gradient marks where the instant occlusion (warm front) forms, the lack of a continuous discontinuity suggests that a Type 2 instant occlusion cannot be formed from wave tip to cold low as required. The two earlier runs suggested that instant occlusion merging was more likely (especially the earlier) and both developed strong 850 mb θ_w gradients from wave to cold low.

Application of the manual forecasting guidelines around 0000 UTC on 1 May would have indicated the possibility of a Type 2 situation, using satellite imagery and surface observations. Spacing from trough cloud to wave tip at this time was around 500 n mile and consideration of the upper flow would have implied that this spacing would not decrease much. Thus, instant occlusion formation was not suggested by the guidelines. Measurements from the infra-red imagery indicated that the appropriate part of the trough cloud was at least 400 n mile from the wave cloud at its closest point — during the period 1500–1800 UTC on 1 May.

4. Conclusions

Like all atmospheric processes, the factors which control whether a polar trough and a frontal wave will merge are finely balanced and these three case-studies have illustrated the difficulties of assessing development probabilities with limited information in data-sparse areas. Satellite imagery has been shown to play an essential role in this process, coupled with guidance from NWP models, though both require careful interpretation. The two cases of actual instant occlusion development demonstrated the essential differences between the Type 1 and Type 2 categories and the third case, where an instant occlusion did not form, confirmed the concept of critical system spacing and also revealed the importance of the SMZ boundary structure as a significant indicator in potential Type 2 cases.

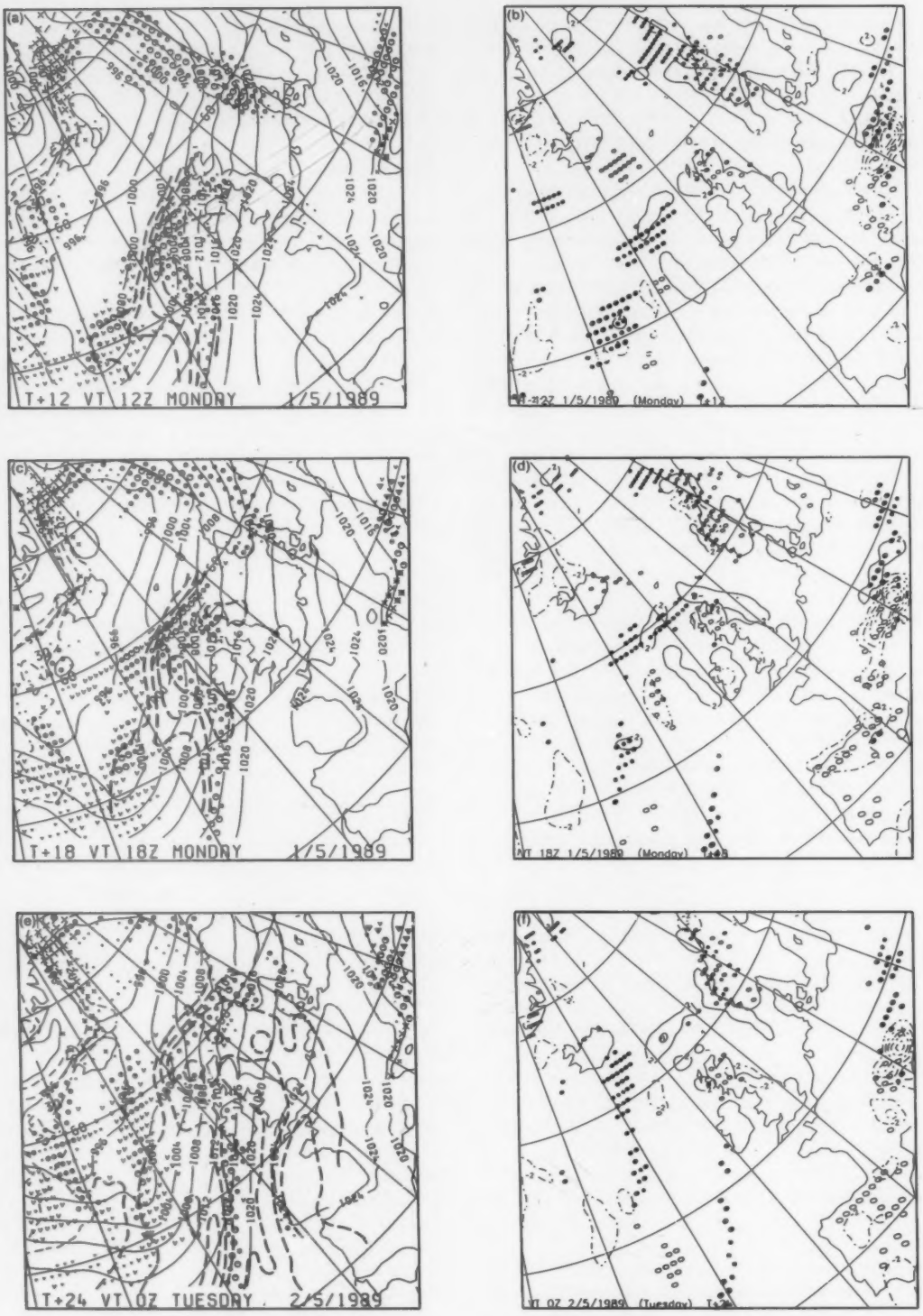


Figure 14. As Fig. 7 but for Data Time 0000 UTC on 1/2 May 1989. Rainfall rate and m.s.l. pressure: (a) Verification Time (VT) 1200 UTC on 1 May, (c) VT 1800 UTC on 1 May, and (e) VT 0000 on 2 May. Model diagnostics: (b) VT 0000 UTC on 1 May, (d) VT 1800 UTC on 1 May, and (f) VT 0000 on 2 May.

The guidance from the chosen fine-mesh model runs was impressive in most respects. In all three cases, instant occlusion development (or not) was correctly indicated and the model clearly and reliably distinguished between Type 1 and Type 2 situations; the resulting weather and cloud patterns were represented satisfactorily. The main fault came with timing errors of up to 5 hours or so within T+18 to T+24 hour forecasts; however, the assessment of actual merging times will also certainly be subject to some degree of error. In the third case-study, when the possibility of instant occlusion development was maintained at a critical stage for an extended period, the model solution correctly indicated the finely balanced nature of the interactions and provided the correct guidance that instant occlusion formation would not occur. It is significant to note that earlier model runs (DTs 12 and 24 hours previously) were generally more unsuccessful in their predictions, especially in timing/positional errors; these were due mostly to the development of synoptic-scale errors. However, instant occlusions of the correct type were predicted in the first two cases and the third case produced differing opinions on whether merging would occur; this generally confirmed the much-discussed interaction spacing concepts. In particular, the importance of the SMZ, as indicated by a correctly located strong gradient of 850 mb θ_w, was demonstrated by the model fields; *inter alia*, such a gradient is an essential requirement for Type 2 instant occlusion development.

It is clear that the fine-mesh model predictions are a valuable source of guidance for the forecaster when there is a possibility of instant occlusion development. In addition to giving advice on placement and timing, the model fields should help to establish whether instant occlusion development is likely and, if so, whether this will be a Type 1 or a Type 2. The interpretation process should include careful examination of the thermal fields, especially the 850 mb θ_w gradients, to establish or confirm which type of instant occlusion is likely. Although the case-studies made use of a whole range of forecast products available from the model, it is suggested that both types of instant occlusion development can be well identified from the first three output fields listed in Section 3 of this paper; these fields will normally be available to the forecaster on a routine basis.

The manual forecasting guidelines (Section 2) appeared to perform successfully in two out of the three cases. The modification made to the original guidelines operated reliably, indicating whether a Type 1 or Type 2 situation was possible. In the first case, the highly developmental nature of the situation, with its extremely rapid eastward movement, defeated the guidelines which can only be applied to existing troughs and waves. In this case, the new PVA development was close enough to the front to interact immediately and the instant occlusion was formed as the development strengthened. The second and third cases were correctly predicted by the guidelines. The cases here indicated that the critical distance for merging to commence may well be somewhat less than the 350 n mile stated but the evidence is hardly conclusive due to the uncertainties in measurement. It is therefore confirmed that 350 n mile is a reasonable figure to apply.

It is suggested that the main use of the manual forecasting guidelines will be at DTs some 24 to 36 hours before the possible instant occlusion event. At these times, the case-studies presented here have indicated that the fine-mesh model is much less successful in predicting instant occlusion events correctly and the application of the guidelines at these times should provide a useful confirmation (or otherwise) of the model solution. At DTs 12 to 24 hours before the event, the increasing reliability of the model predictions will diminish the importance of the guidelines, although their use may still be regarded as a valuable check on the model.

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References

Anderson, R.K., Ashman, J.P., Bittner, F., Farr, G.R., Ferguson, E.W., Oliver, V.J. and Smith, A.H., 1969: Application of meteorological satellite data in analysis and forecasting. Washington DC, Air Weather Service, Technical Report No. 212.

Böttger, H., Eckardt, M. and Katergiannakis, U., 1975: Forecasting extratropical storms with hurricane intensity using satellite information. *J Appl Meteorol*, **14**, 1259–1265.

Browning, K.A. and Hill, F.F., 1985: Mesoscale analysis of a polar trough interacting with a polar front. *Q J R Meteorol Soc*, **111**, 445–462.

Gadd, A.J., 1985: The 15-level weather prediction model. *Meteorol Mag*, **114**, 222–226.

Locatelli, J.D., Hobbs, P.V. and Werth, J.A., 1982: Mesoscale structures of vortices in polar air streams. *Mon Weather Rev*, **110**, 1417–1433.

McGinnigle, J.B., Young, M.V. and Bader, M.J., 1988: The development of instant occlusions in the North Atlantic. *Meteorol Mag*, **117**, 325–341.

Marshall, T.A., 1982: Weather satellite picture interpretation, Vol. 2. London, Ministry of Defence, Directorate of Naval Oceanography and Meteorology.

Monk, G.A. and Bader, M.J., 1988: Satellite images showing the development of the storm of 15–16 October 1987. *Weather*, **43**, 130–135.

Reed, R.J. and Blier, W., 1986: A case study of comma cloud development in the Eastern Pacific. *Mon Weather Rev*, **114**, 1681–1695.

Weldon, R.B., 1979: Cloud patterns and the upper wind field. Satellite training course notes, part IV, pp. 62–79. Scott AFB, Air Weather Service, Report No. WAS/TR-79/003.

Young, M.V., 1988: Investigation of an instant occlusion event during FRONTS87. (Unpublished, copy available in the National Meteorological Library, Bracknell).

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Developments in meteorological telecommunications

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Summary

A brief description is given of recent developments in meteorological telecommunications with particular reference to the operation of the Bracknell Meteorological Telecommunication Centre.

1. Introduction

The application of 'new technology' to telecommunications offers many possibilities for the improvement of data exchange between meteorological centres. The functions of the Meteorological Telecommunication Centre (Met TC) at Bracknell are continually expanding as data volumes increase and new types of data are made available for transmission between centres. New methods of transmission using digital techniques and new communications media such as fibre-optic cables can provide higher data rates at lower cost than the existing analogue circuits. Modern technology has also enabled the development of interface units to handle high-speed transmissions for even quite low-cost processing systems.

Allied to the introduction of new types of equipment are the evolving international standards for data handling and data management which enable users to benefit from the capabilities of the new systems without large development costs. These standards aim to provide common interfaces to allow equipment from different manufacturers to work together. The availability from suppliers of software packages, which implement the standards, facilitates rapid integration of new systems and the wide customer-base for such products reduces the cost for individual users.

2. Functions of the Met TC

The Met TC at Bracknell supports the national networks and handles most of the communications between the Meteorological Office and the rest of the world. The principal functions are collection of observational data from UK outstations, distribution of these data and some forecast products to the outstations and exchange of observational data and forecast products with other meteorological centres. These functions are carried out 24 hours per day, every day of the year.

The national observational data are collected from outstations via collecting centres from where bulletins of reports are sent to Bracknell over dedicated circuits. These data together with a selection of forecast products are sent back to the outstations over teleprinter and facsimile circuits. Fig. 1 shows the main links in the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO).

The international communications use networks — in particular the WMO GTS — which provide medium-speed links and allow exchange of global information between the major data processing centres and facilities for supplying a more limited range of products to less well equipped National Meteorological Centres (NMCs). Bracknell acts as a Regional Telecommunication Hub (RTH) situated on the WMO Main Trunk Network between Washington and Paris with whom large quantities of data are exchanged daily. Bracknell also has connections to Offenbach, to the European Centre for Medium-range Weather Forecasts (ECMWF) and to several other centres in countries which are part of the UK area of responsibility for collection of observations and supply of data to their NMCs.

Fig. 2 shows the steady growth in traffic handled by the Met TC over recent years, amounting to an increase by a factor of 40 from 1972 to 1989. This is due to increased volumes of observational data and more, higher-resolution output products from numerical weather prediction models.

3. Data handling systems at the Met TC

Different types of data are handled by different computer systems within the Met TC. Graphical data are handled by Autofax, a dual Ferranti computer system, and alphanumeric and binary data by the Phase IV, Tandem computers, the main message switching system.

3.1 Autofax

The Autofax system consists of two Ferranti Argus 700GX computers. Normally one of these provides the operational services whilst the other is available as standby in case of failure and can also be used for software development. The system drives all the analogue facsimile services which are received at outstations, such as MOLFAX (Meteorological Office Landline Facsimile), and also provides a digital broadcast of pictorial products for GRAFNET (see section 5). The products for dissemination by the

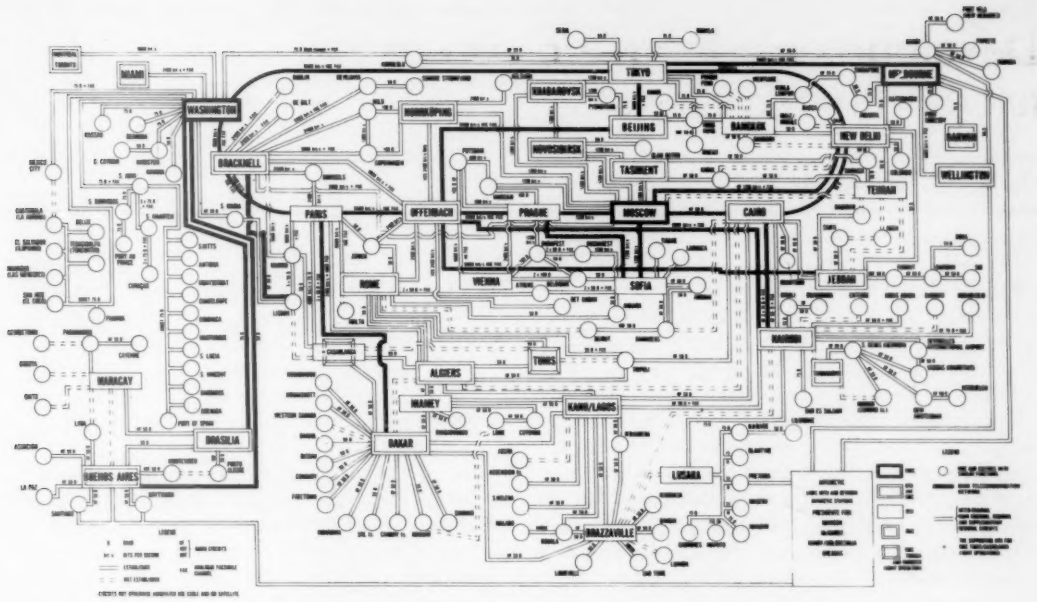


Figure 1. Schematic diagram of the Global Telecommunication System of the World Meteorological Organization.

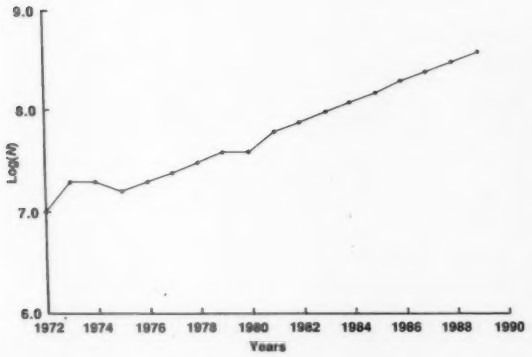


Figure 2. The logarithmic growth of traffic handled by Bracknell Meteorological Telecommunication Centre in recent years. N is the number of characters (including bit-orientated data) exchanged daily.

Meteorological Data Distribution (MDD) mission are also supplied from Autofax (see section 6.2).

3.2 Phase IV

The Phase IV system is a seven processor Tandem TXP Non-Stop II system. It came into operational use in 1986 with five processors and was enhanced by the addition of two more processors in 1987. Owing to the increased volume of message traffic the disk space has been increased to one gigabyte. The disks are run as mirrored pairs and other hardware and connections are duplicated to provide resilience and non-stop capability. Failure of any system component should result in graceful reconfiguration without loss of data or programs.

The Phase IV and Autofax systems were designed as message switches and are not concerned with the content of messages provided that they are correctly formatted and can be routed to their destination. Both are linked at high speed to the main data processing systems, COSMOS, to receive data for transmission.

All the international data links are supported from Phase IV. Also there are links to Meteorological Office outstations, to customers such as airlines and the Civil Aviation Authority (CAA) and to other Government bodies, e.g. the Department of the Environment which receives nuclear monitoring data via the Radiation Incident Monitoring Network. Data that are received are transmitted to COSMOS for analysis and use in the numerical forecast models. Most of the national links to outstations are only used for small amounts (a few kilobytes) of data. This will change with the introduction of the Weather Information Network (WIN) when large amounts (several megabytes) of data will be supplied to the Outstation Display Systems at Meteorological Office locations in the United Kingdom. The WIN will be supported by a Bracknell communications node and there will be a back-up node. Data for distribution will be supplied from Bracknell and also from the Autosat-2 computers at the satellite data receiving station at Lasham operated by a contractor on behalf of the Royal Aerospace Establishment and the Meteorological Office.

The main data flows in Phase IV are, currently, to and from the GTS and these links are gradually moving to higher speed lines and more sophisticated protocols to cope with the increased data rates. There is a need for

error detection and correction during transmission and receipt of forecast products and observational data.

4. Standards in international telecommunications

There are continuing discussions between the major GTS centres about the future development of international meteorological communications. International communications standards are being developed by bodies such as the International Telegraph and Telephone Consultative Committee (CCITT) and the International Standards Organization (ISO). The CCITT has developed the X series of recommendations for communications protocols. Two of these, X.25 and X.400, are discussed below. The ISO has a seven-level reference model (Fig. 3) for the interconnection of open systems which divides the logically homogeneous functions performed by different communicating equipments into a hierarchical structure. It describes the communications functions from the lowest, physical, level to the level 7 application program interface. All these standards are designed to allow equipment from different manufacturers to communicate effectively.

4.1 CCITT recommendation X.25

X.25 is a protocol for the lower levels of the ISO model — up to level 3 in Fig. 3. It splits the data into high-level data-link control frames with headers giving address and control information (Fig. 4). Each level accepts information from a higher level and adds a header and sometimes a trailer before passing the information to the next level down as shown in Fig. 5.

Advantages of X.25 are that the protocol provides for the exchange of data in binary form, error detection and control, and the ability to control data flow to avoid congestion on the link or loss of data when the receiving system is not ready for more data. Sequence checking of received frames is performed and the link can be disconnected, reset and restarted.

It is also possible to use several logical channels on one point-to-point X.25 connection. This can be used to separate different types of data. Each channel can be flow controlled and error checked independently of any other logical channels.

At the Bracknell RTH there are a few international links which still use WMO protocol (a character based protocol) but the links to major centres are being converted to X.25 protocol running at speeds of 2.4 to 9.6 kilobits per second (kbps). All of these X.25 links to Phase IV use permanent virtual circuits (PVCs) on leased lines which are continuously available and ready to transfer data. The alternative to a PVC is a switched virtual circuit (SVC) which only needs to be established when required for data transfer. The transatlantic link to Washington, used for exchange of GTS data and World Area Forecast Centre (WAFC) aviation products, consists of a number of separate physical channels Time Division Multiplexed (TDM) on to a 16.8 kbps link. One of these channels is further subdivided into two logical channels to aid in separation of different types of data whilst keeping the whole channel running at the highest possible capacity. Each logical channel has independent flow control on the packets and also separate error control.

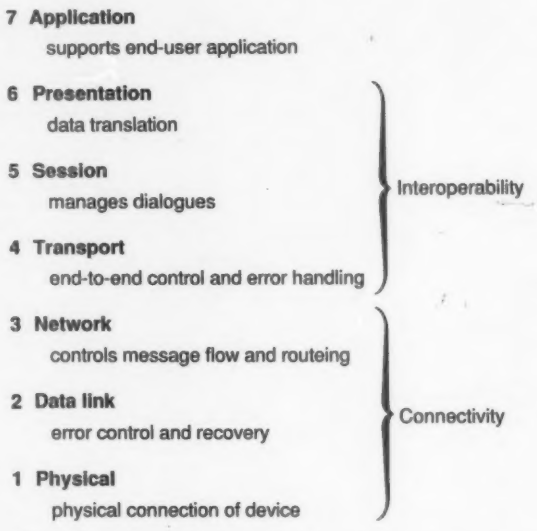


Figure 3. The International Standards Organization seven-level reference model for interconnection of open systems.

The link to the National Weather Service (NWS) at Washington is currently via satellite but is being transferred this year to a new service using a fibre-optic cable across the Atlantic. This new link will operate at the higher speed of 64 kbps and will have separate TDM channels for different data types. As well as GTS data, the circuit will carry digital facsimile products and special satellite data from the National Environmental Satellite Data and Information Service in Washington. This service is cheaper than the corresponding satellite service, provides more security and allows more control.

The implementation of X.25 protocol on links to Phase IV follows the recommendations for the ISO lower layers 1–3. The addition of transport-layer protocol (layer 4) to provide end-to-end confirmation of message delivery was considered by representatives of WMO Members but the software for this is not yet standard for all manufacturers.

In future there will be increased quantities of data and plans are being made for migration of other international circuits, such as those to Paris and Offenbach, to 64 kbps lines which will be subdivided into channels in similar manner to the Washington link. In the longer term only logical separation of data will be used over a single channel thereby providing increased efficiency.

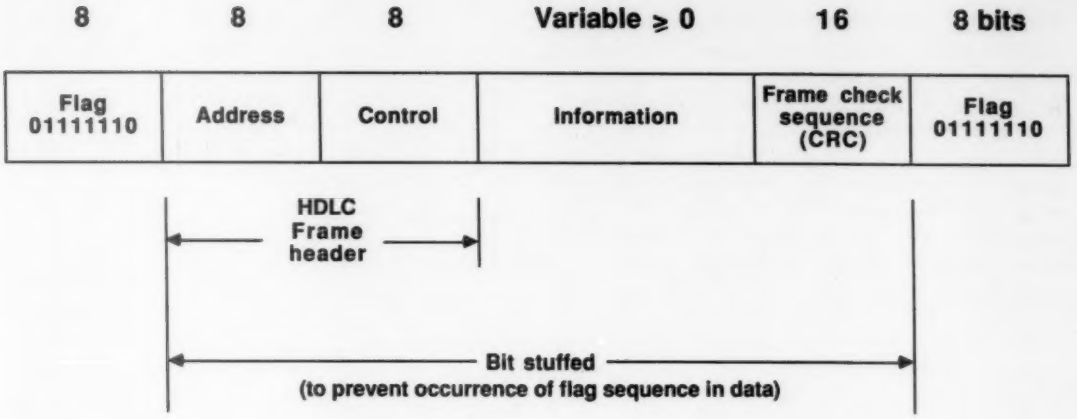


Figure 4. The format of a high-level data link control (HDLC) frame in the X.25 format. CRC is cyclic redundancy check.

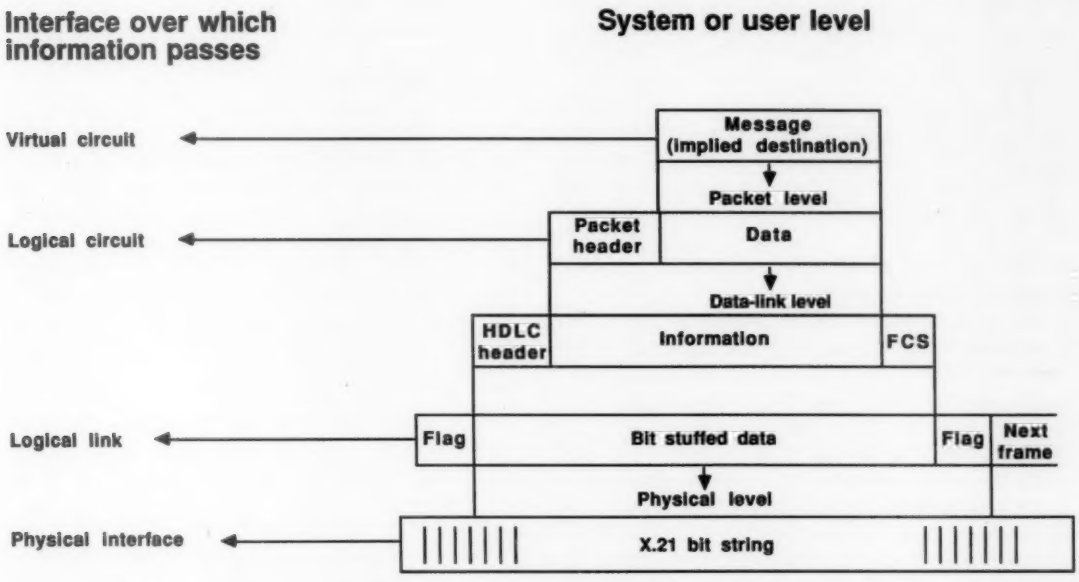


Figure 5. Structure of frame in Fig. 4 showing separate levels. FCS is frame check sequence.

The need for back-up, particularly during an outage of one of the major GTS centres, has to be considered. For this, and to allow flexibility in reconfiguring circuits, the use of packet switches at each centre and SVCs instead of PVCs was recommended. Because the use of SVC includes call set-up, the links can use dial-up connections over public data networks if the leased lines are not available. Large and small messages can be separated by the use of multiple virtual circuits on each connection.

X.25 protocol is used by British Telecom (BT) for its public data network service — Packet Switch Stream (PSS). This provides the ability to transfer data between computers (packet terminals) and other computers or character terminals. Packet terminals have software to handle incoming X.25 packets and to put data into packets before transmission. Character terminals, which do not have this capability, are connected to PSS via a Packet Assembler/Disassembler which handles the communications protocol for them. PSS has a gateway to similar systems in other countries, e.g. Transpac in France. This service is used by the Meteorological Office to send data to the National Meteorological Services in Singapore and New Zealand and to various commercial customers in the United Kingdom and abroad. Facilities of this type offer a very cost-effective way of providing back-up for GTS leased lines and providing low volumes of data to a number of users.

4.2 CCITT recommendation X.400

X.400 is the CCITT recommendation for message handling systems (MHSs). It is a level 7 (application level) protocol. An MHS consists of a set of interconnected Message Transfer Agents (MTA) which cooperate with User Agents (UAs) to transfer messages between end users as shown in Fig. 6. A message has a content and an envelope which is similar to, but more sophisticated than, the headings added by X.25. There are additional facilities such as message stores to hold data for later examination by a user and access to other services, e.g. physical distribution. Some features of X.400 will be very useful, especially for WIN. These include distribution lists and directories which allow selective distribution of messages and format conversion to, for example, facsimile or graphics. Each user is registered on the system and messages are converted into suitable format for handling by the available equipment.

X.400 will be considered for use on the GTS when centres have gained experience with it for national communications. A number of X.400 services are available from both public and private operators.

The service offered by BT using X.400 is called Gold 400. It provides access from customer terminals or computers, via gateways, to a range of services such as fax, telex and the international network. It also interfaces to the BT mailbox system Telecom Gold.

5. Automation of facsimile product handling at Bracknell

Facsimile products which are produced from charts on the main data processing system, COSMOS, are sent from COSMOS to Autofax in digital form but they can be transmitted from Autofax to either digital or analogue receivers. To reduce transmission times the charts are sent as compressed bit-maps from COSMOS. Originally they were sent in a special code which compresses the bit-map to about one third of its length. Lately the T.4 coding recommendation of CCITT has been adopted. This reduces the bit-map to about one seventh of its original length. The charts are decoded on Autofax before being converted to a special compression code for the Facit printers on GRAFNET or being sent on the analogue broadcasts.

In future there will be a requirement to transmit charts in T.4 code for use by the CAA and also for the MDD mission. This is described later.

Other charts are hand drawn rather than produced on COSMOS. These have to be scanned in via a scanner attached to a personal computer (PC) then transferred using X.25 to Autofax before they can be retransmitted. Charts such as significant weather are required in T.4 code for the CAA and MDD and work has been done with an A4 scanner and a PC interface card to produce T.4 coded images directly. This is shown in Fig. 7. An experimental PC system which holds images in store so that they can be retrieved by an authorized caller using

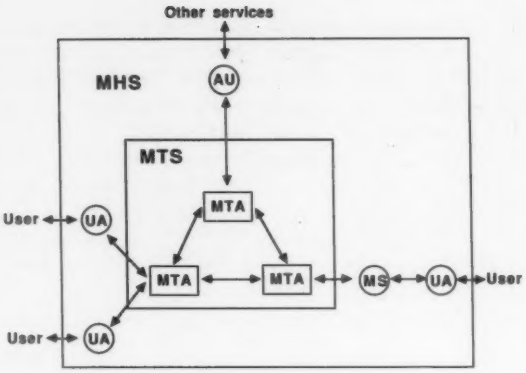


Figure 6. The X.400 message handling protocol. MTS is the Message Transfer System, MS a Message Store, AU an Access Unit. Other abbreviations are explained in the text.

standard Group 3 facsimile equipment has also been demonstrated, and will be developed further to serve commercial customers.

6. Satellite systems

6.1 DCP data collection and OWSE-AF

The Meteosat satellite is used for collection of environmental data from automatic and semi-automatic weather stations located on land (Data Collection Platforms (DCPs)), at sea (Automated Shipboard Aerological Programme (ASAP) and Meteorological Office System for Ships (MOSS)), or in aircraft (Aircraft/Satellite Data Relay (ASDAR)). This Meteosat Data Collection System (DCS) is part of an international DCS using other satellites. The DCP transmits its data

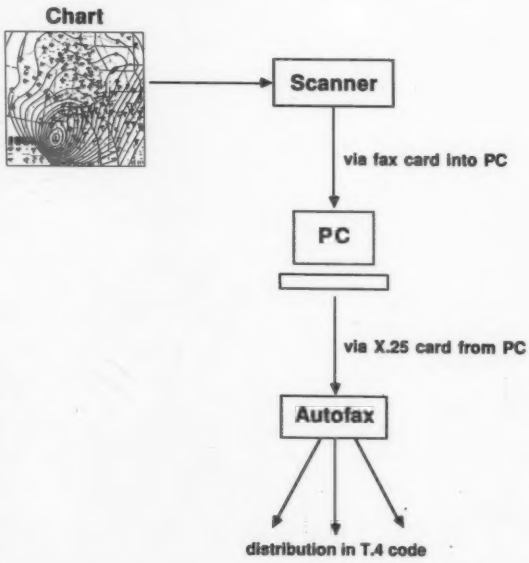


Figure 7. Conversion of image data into T.4 code and its distribution.

to the satellite at predetermined times and all the data are sent to the European Space Operations Centre's Data Acquisition Telecommand and Tracking Station (DATTS) as in Fig. 8. From there the data are sent to Darmstadt for distribution by land-based communication systems (e.g. GTS) and a selection of the data is sent back to the satellite via the Data Relay System (DRS) for broadcast to user stations in the gaps between the Wefax (image) frames.

The Meteorological Office has automatic weather stations (AWSs) using DCPs to report in a national code from buoys and also similar AWSs are replacing manual reports from Light-vessels. These observations are received from Darmstadt and are code converted to SYNOPs in Phase IV before to distribution.

Plans are under way for a study of the meteorological data exchange requirements in Africa — this is the Operational World Weather Watch Systems Evaluation Africa (OWSE-AF). The aim is to improve the collection and distribution of data in the WMO Regional Association I area (Africa). Initially the suitability of DCP/DRS systems for use in Africa will be evaluated and later the effectiveness of a satellite based dissemination service will be studied (see Fig. 9).

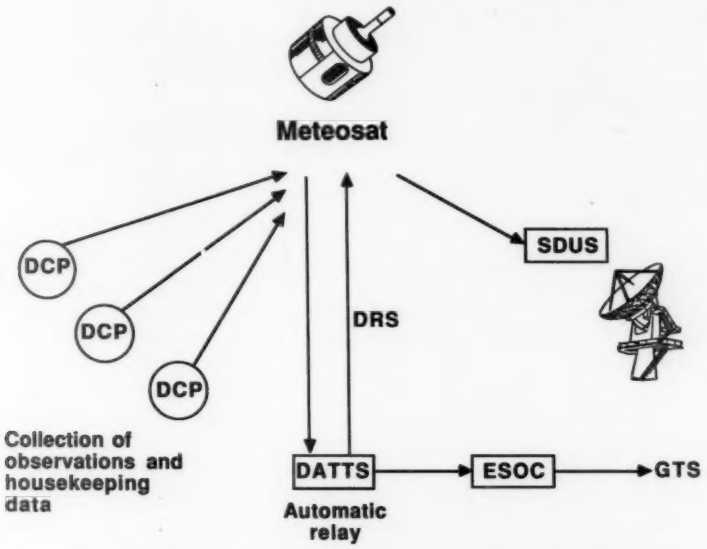


Figure 8. Meteosat Data Collection Platform System. SDUS is a secondary data users' station. Other abbreviations are explained in the text.

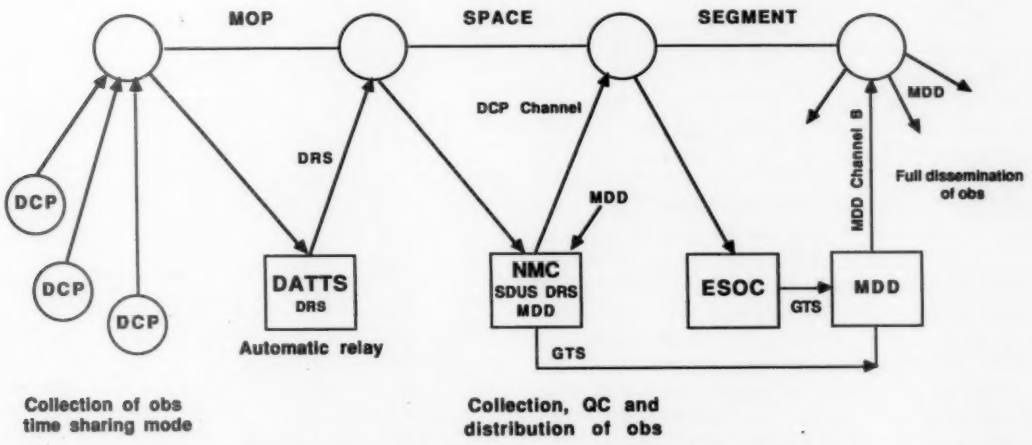


Figure 9. The Operational World Weather Watch System Evaluation Africa (OWSE-AF); a possible use of DCP, DRS and MDD missions for observation collection and distribution.

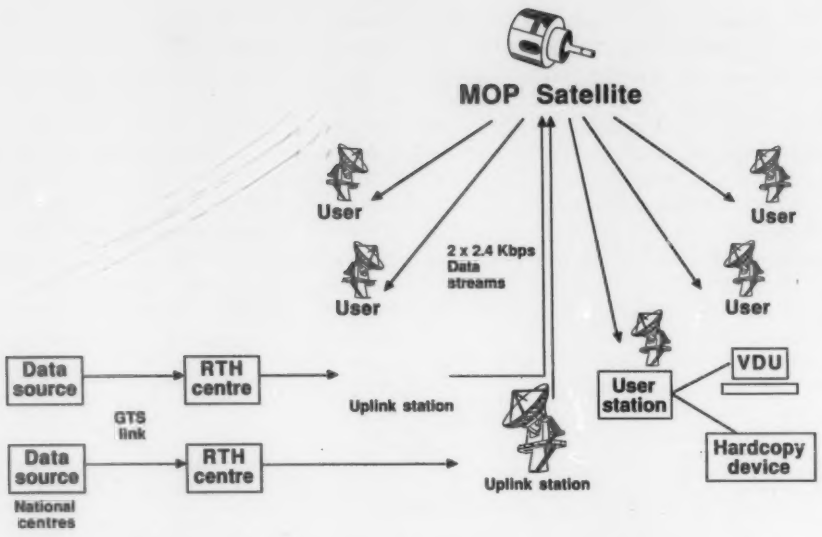


Figure 10. The Meteorological Data Distribution mission concept. Abbreviations are explained in the text.

6.2 Meteorological Data Distribution

The MDD mission has been set up primarily to provide meteorological data to national meteorological services in Africa and the Near East. It will use the new Meteosat Operational Programme satellites, the first of which was launched last year. Four satellite communication channels have been reserved for MDD although only two will be used to start with. A ground station at Bracknell will use one channel to transmit coded facsimile data and a similar station in Rome will send alphanumeric data on a different channel. Both these data streams will be 2.4 kbps (Fig. 10). There are plans to encrypt the data to restrict its use to authorized receivers though this would reduce the effective data rate and a study on encryption is being carried out for the European Space Agency.

Receiver stations will be equipped with a user station, micro-processor, data store, visual display unit and hard copy device. Although orientated towards African users the broadcast will be able to be received by similar systems in Europe, the Caribbean and parts of South America.

6.3 Commercial satellite systems

As well as communication via Meteosat there are also commercial companies offering a variety of satellite data distribution systems. These usually have a central transmitting station to which customers send their data by conventional means and these data can then be broadcast to reception equipment at customer sites. Two-way communication is possible via the satellite, provided that the customer sites are equipped with a suitable transmitter (Fig. 11). The data can be protected from unauthorized use by encryption. Several WMO members use such systems for their national networks. The political, financial and organizational aspects of the use of such systems internationally needs consideration at all levels in WMO.

The INMARSAT service for collection of SHIP observations is proving most valuable although there are areas, particularly the Indian Ocean, where no WMO Member has offered to accept reports via an appropriate Coast Earth Station (CES). At Bracknell about 130 reports are accepted each day using a special short dialling code. This represents about 40% of the

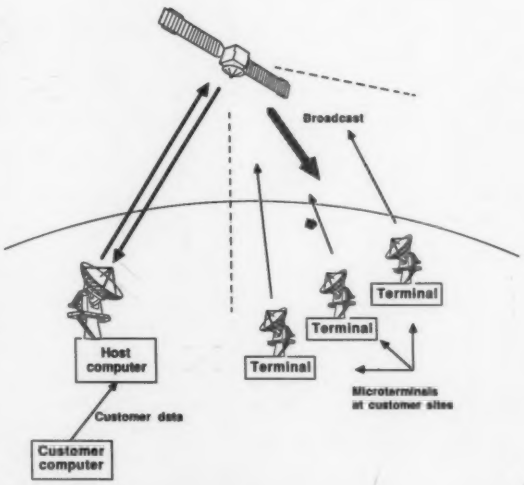


Figure 11. Commercial satellite broadcasting.

reports collected. Bracknell has also participated in the Enhanced Group Call system which is to be used for the INMARSAT SAFETYNET service which will form part of the Global Maritime Distress and Safety Communications system organized by the International Maritime Organization (IMO). Input of meteorological warnings and forecasts for the oceanic areas to the system is through direct communication with the CES, very much on the lines of information provided to Coast Radio Stations under NAVTEX.

7. Conclusion

Continuing increases in the volume of data to be handled on both national and international links in the Met TC are anticipated as more observational data such as that from satellites becomes available, higher-resolution model products are generated at major centres and more specialized products are made available for customers. These will require the development of the existing systems and also investment in new technology as it becomes widely available. Various systems for providing effective communications links have been described above. The availability of satellite-based systems for point to multipoint transmissions is growing rapidly and the use of such systems can be very valuable to the meteorological community. The use of these communication methods will be examined as the need arises.

Awards

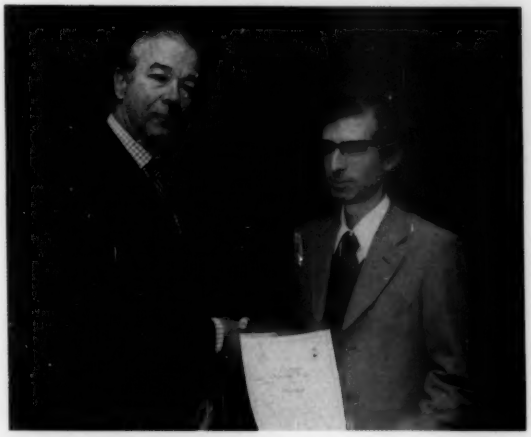
L.G. Groves Memorial Prizes and Awards for 1988

These awards were instituted in 1946 by Major and Mrs Keith Groves in memory of their son, Sergeant Louis Grimble Groves RAFVR, who lost his life while flying on a meteorological sortie with 517 Squadron on 10 September 1945. The 1988 awards were presented by Mr Andrew Douglas-Bate (a relative of the Groves family) on 8 December 1989 at RAF Brampton, HQ RAF Support Command, and the citations were read by the Inspector of Flight Safety, Air Commodore G.R. Profit, OBE, AFC, RAF.

Meteorology Prize — Dr B.W. Golding

The citation for this award was:

'Local-scale forecasts for periods of 12 hours or so ahead are important for many weather-sensitive activities. This is particularly true for aviation; civil aircraft need to know details of the wind, temperature, visibility and cloud base near the ground both for flight safety during take-off and landing and for effective management of airline operations; military aircraft are also sensitive to small-scale weather features, especially during low-level flying when factors such as precipitation, wind shear and icing are particularly important. The Meteorological Office's mesoscale model, which has a horizontal resolution of 15 km and a detailed representation of the structure of the atmosphere at low levels, has been designed to provide improved guidance to forecasters in the outfield on such local weather conditions. Over the past 7 years Dr Golding has successfully transformed the model from a research tool into a potentially important practical component of the Office's operational numerical weather prediction system. The model's wind and temperature forecasts are recognized as already being very accurate; modifications to improve the predictions of more difficult quantities such as cloud, rainfall and visibility will be introduced prior to the



operational implementation of the model on the Office's new Cray supercomputer. The model's forecasts are much appreciated by those forecasters who have already received them on a trial basis.

'The provision of sufficiently detailed input data for the model has posed special problems because the model's 15 km resolution is much finer than the distribution of observing stations. Also, some of the model's variables, such as the liquid water content of clouds, are not observed by the routine meteorological observing system. Dr Golding has conceived, designed and implemented a system which displays radar rainfall and satellite cloud pictures on a screen together with computer analyses of conventional observations. Forecasters are then able to interactively adjust and merge data from different sources to obtain the best possible initial conditions for the model. Both the model itself and the interactive initialization system provide the Meteorological Office with a facility that is unique in the world of meteorology.'

Award for Meteorological Observations — Mrs J. Harmer

The citation for this award was:

'Since Mrs Harmer joined the Meteorological Research Flight in 1983 she has made important contributions to the collection of airborne meteorological observations. She has flown many times as Flight Leader, co-ordinating the collection and verification of data from the aircraft instruments. This task demands persistent concentration and awareness in uncomfortable conditions. During the July 1988 detachment to Dakar, Senegal, she was Flight Leader on every mission, requiring intensive flying for long hours, and her consistently good performance was a large factor in the eventual success of the experiment. Mrs Harmer has also been responsible for the meticulous but essential task of maintaining the high quality of the measured data. This has culminated in the implementation of a new on-board system for displaying observations as they are taken, a project of considerable complexity which she developed herself using her knowledge and understanding of the aircraft instruments and their operation. The main phase of the project was completed in 1988 and now provides a powerful tool for making and monitoring observations during flight.'

Reviews

Earth's changing climate and **Our drowning world** (second edition), by A. Milne. 142 mm × 223 mm and 134 mm × 215 mm, pp. 167 and 176, *illus*. Bridport, Dorset, Prism Press, 1989. Prices £12.95, $17.95 and £5.95, $10.95.

Environmental scientist Antony Milne's book *Earth's changing climate – the cosmic connection* is published simultaneously with the second edition of his earlier work *Our drowning world*. Both books are intended for a general readership.

Earth's changing climate aims to demonstrate the major effects of 'extra-terrestrial forces' and the role of both uniformitarian and catastrophic influences on earth's climate and history. The book is divided into three, somewhat blurred, sections which together cover magnetic influences, the Jupiter effect, the evolution of the sun, sunspots, the Milankovitch theory, volcanic forcing and impact extinction theories. There is no general introduction to climatic history or processes and it is hard for the general reader to distinguish between the different time-scales under discussion. The author himself seems somewhat confused about earth's history and what we do and don't know about different events. No distinction is made between, for example, the Pleistocene Ice Ages (which can be adequately explained by the Milankovitch theory) and those of the Pre-Cambrian.

Only in the Epilogue does the author admit that many of these 'entertaining and plausible' theories are speculative. Yet, on the same page, he claims they all have a '50-50 chance of being correct'! The real problem with this book is that it is impossible for the reader to distinguish between theories which are (a) widely accepted, e.g. the Milankovitch theory, (b) controversial, e.g. the sunspot-climate link, and (c) wild flights of fancy, e.g. the effect of planetary alignments on human personality.

Similar problems beset *Our drowning world*, the sleeve-notes of which talk of an apocalyptic thesis. The first section of this book attempts to describe the environmental impacts of population and urban growth, atmospheric pollution (including ozone and CFCs), deforestation and the greenhouse effect. The concept of the greenhouse effect and the ability of scientists to predict its impacts are not particularly well described. The second section opens with a catalogue of recent extreme events and a brief discussion of two potential climate change mechanisms (orbital forcing and sunspots) before going on to consider the impacts of greenhouse-gas-induced warming on sea level. The societal impacts of large rises in sea level are then discussed at some length, while ecosystem impacts are given more cursory attention. This latter chapter closes with a description of future UK summers when, drawing a parallel with 1976, 'fewer British men will be growing beards or wearing ties'!

It could be argued that, in a popular text like this, the specialist should be prepared to accept some simplification and exaggeration and maybe even to tolerate some factual errors, but only up to a certain point. That point is overstepped many times in *Our drowning world*. In

chapter 9, for example, the author claims that there is a general concensus that sea level will rise by about 20 feet by 2100. Of which group this represents a general consensus I am not sure. Worse still, the same chapter includes two maps, not mentioned in the text, which show the extent of European and eastern USA flooding with sea level rises of 200 and 250 feet respectively! The factual errors become too numerous to ignore: the Laurentide ice sheet does not include the Fenno-Scandinavian (page 118), 1645–1715 is the date of the Maunder Minimum and not the Little Ice Age (page 98) ... and so on.

The general public are becoming more and more concerned about potential climate change and other environmental issues. In order to make fully informed decisions about energy policy and sensitive issues such as the defence or abandonment of coastal areas we need accessible, well written and researched, responsible books. Unfortunately *Our drowning world* is not one of these. This is perhaps not surprising given the list of references: this relies too heavily on newspaper and popular magazine articles and not on the best of the new scientific literature. Sea level rise is presented as an inevitable catastrophe about which we can do nothing. There seems little hope of early or successful international government action on environmental problems if this fatalistic view becomes widely held.

If I had to give one of these two books to a friend to read I'd pick *Earth's changing climate* and a large pinch of salt. It does at least give something of the feel of the complexities of the earth's climatic history and its future.

C. Goodess

Weather radar and the water industry, by the British Hydrological Society. 208 mm × 295 mm, pp. ii+91, *illus*. Wallingford, Oxfordshire, Institute of Hydrology, 1989. Price £12.00.

This Occasional Paper of the British Hydrological Society summarizes the proceedings of a meeting at which the state of the art of weather radar in the United Kingdom and its current and future use in the water industry were discussed. The meeting was organized by the Natural Environment Research Council (NERC) Steering Committee on Hydrological Applications of Weather Radar. Eight papers were presented by experts in rainfall data provision and application. They review investments and achievements to date and provide revised and new assessments of potential uses and benefits of radar data to the water industry in the 1990s.

In the first paper Collinge examines investment in the radar network by the water industry. Contrary to previous cost-benefit analyses Collinge includes both costs of research and development and of deferring benefit until adequate research is completed. Additional benefits such as reduced traffic dislocation and better flood warning are also included. From his study Collinge suggests a new benefit/cost ratio of the radar network to the water industry of 3.0–3.5.

It is unusual in many radar texts to find a simple technical description of the radar system. However an excellent description of the principles, aims and limitations of the UK radar system is given by Lawler.

In the following two papers the uses of radar as a tool to measure and to assist in the forecast of precipitation are discussed. In an interesting and well written paper Moore considers measurement of precipitation by radar. He places particular emphasis on perceived problems with the existing radar measurements. He reviews recent investigations of local recalibration of radar, by telemetry gauge networks, prompted by the suggested accuracy requirements of the precipitation measurements used by the hydrological community.

The use of radar as a tool for short-period weather forecasting is examined by Collier. The most commonly employed short-period extrapolation techniques and associated problems are identified. Suggested future developments include using meteorological forecast model products such as storm-steering-level wind to improve storm extrapolation techniques. Assimilation of radar data into forecast models is also envisaged.

Many of the topics of the preceding two papers are considered within the context of flood warning by Haggett. He presents a brief outline of progress in this field from the Dee Weather Radar project in the 1960s to the establishment of the existing radar network. The recent trend towards quantitative requirements such as subcatchment totals is explored and expected growth areas of local calibration, short-period forecasting, snow measurements and distributed flow forecasting models are discussed.

In the following paper, Cluckie and Tyson explore further the potential for use of quantitative radar data in urban systems. A brief overview is given of three international projects associated with storm recognition and drainage management. Detailed summaries of progress in British research are provided. Particular attention is given to the use of *Wallingford Storm Sewer Package* (WASSP) and other drainage models and to the impact of intensity resolution of the input rainfall data to such models.

A complementary paper by Reed and Stewart considers rural storm hazard assessment. Good statistical analysis of storm hazard is required for engineering and environmental hazard assessment. After briefly describing the technique for return-period assessment commonly used, based on the *Flood Studies Report*, the authors highlight the problem of insufficient regional variation that can occur with this technique. An alternative method aimed at reducing the problem of spatial dependence in hydrological extremes is proposed. The role of radar is seen primarily as one of providing sub-daily rainfall at a higher resolution than is possible with the existing gauge network. The use of geostatistics in conjunction with radar is advocated.

In the final paper Walsh considers research needs and commercial opportunities for radar in the water industry. The NERC Radar Steering Committee has identified radar calibration, flow forecasting, urban applications and archiving as areas requiring research. The projects being undertaken under the first three topics are listed. The problem of establishing funding and instigating fundamental research in the United Kingdom within the next 5–10 years is highlighted. The paper ends with a series of challenging and important questions as to how investigations can be best organized to meet the research requirements and commercial opportunities of the next decade.

Published soon after the meeting, this document provides a valuable statement on the current state of development of radar and its use to the water industry. There is only slight overlap on basic points between papers. The content is primarily review material and speculation of future advances. It is well written with ample reference material. It provides useful information presented in a fairly simple way for anyone interested in the hydrological application of weather radar. The reader is given up-to-date information about successes and problems of radar use in the water industry. The challenge to use quantitative rainfall estimates in a wide range of applications must be met if the full benefit of radar is to be exploited. This document enhances appreciation of the scale of this challenge and of the resources required to face it.

M.F.Mylne

Noctilucent clouds, by M. Gadsden and W. Schröder. 157 mm × 240 mm, pp. ix+165, *illus*. Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Springer-Verlag, 1989. Price Dm. 138.00.

Noctilucent clouds — a new volume in the 'Physics and Chemistry in Space' series — is an excellent distillation of the history and science of this beautiful upper-atmospheric phenomenon by two internationally recognized scientists whose expertise and enthusiasm shine through the pages they have written. Their declared aim of bringing together in one volume a summary of present knowledge of noctilucent clouds has been successfully accomplished in an account that is both comprehensive and concise.

The introduction gives a good thumbnail sketch of the appearance and general properties of the clouds which should prove helpful to readers who are not familiar with the phenomenon. The different structural forms are classified and beautifully illustrated in a few well-chosen photographs. The clouds themselves are water-cluster-ions that condense out in a narrow range of heights at the temperature inversion close to the mesopause. 'Night luminosity' occurs when they are critically illuminated by sunlight from below the horizon during nautical twilight.

For the historian, there is a well illustrated section which considers possible sightings going back to the eighteenth century. Interesting though these are, they do not challenge the traditional view that Jesse (1885) was probably the first to recognize the true nature of the clouds and measure their height at 82 km. The classical optical methods used in later observing programmes elucidated the general conditions required for cloud formation, fixed their heights, established their velocities and thus gave much insight into atmospheric dynamics at these heights. They also elucidated the geometry of cloud illumination and showed that the screening height (the lowest height at which grazing sunlight can pass through the atmosphere) is sometimes as low as 7 km. While the above studies have defined most of the physical properties of noctilucent cloud, the authors stress that there is still no agreement about the size of cloud particles. Most spectrophotometric and polarimetric studies suggest a particle size of 0.13 μm or less, whereas some spectrophotometric and direct (rocket-borne) sampling studies indicate a particle size of 0.7–0.9 μm or more. The nature of the particle nucleus is also in doubt, there being no clear evidence whether these are solar ions, terrestrial dust or simply hydrated protons. Despite these difficulties, the authors have presented the evidence impartially with helpful summaries of current views at the end of appropriate chapters.

Having considered the physics and chemistry of noctilucent cloud as an entity, the authors turn their attention in the latter part of their account to other interacting environmental conditions and phenomena. Possible relationships with solar and lunar cycles, airglow, temperature, volcanoes, the underlying tropospheric weather and other phenomena are all considered in detail. These other phenomena include: the aurora, with which there may be an inverse relationship due to dissipation of noctilucent cloud as a consequence of mesopausal heating; internal gravity waves, which may play a major role in generating the wave-like structures in noctilucent cloud; and polar mesospheric clouds, which may be a precursor of noctilucent clouds. The possible role of noctilucent cloud as a sensitive indicator of long-term climatic changes, such as the greenhouse effect, is also noted. With the above exciting new developments in upper-atmospheric research, the appearance of this review is most timely for all with an interest in noctilucent cloud or related phenomena.

The book is well written and nicely produced. Its literary style is simple and lucid; its reading, easy and compelling. The bibliography is exhaustive, the index more than adequate and the text almost free from typographical error. The book is highly commended to all 'dedicated research workers, the interested scientist and the enthusiastic amateur' as a most readable and informative account of noctilucent cloud. It looks set to be a standard text on the subject for some years to come.

D.A.R. Simmons

Global climate change, edited by S.F. Singer. 155 mm × 235 mm, pp. vii+424, *illus.* New York, Paragon House, 1989. Price $34.95.

When I started doing research on the 'greenhouse' effect, people's response to being told my job was often 'Yes, isn't acid rain awful?'. After a few years this became 'Yes, isn't the ozone hole awful?'. Now even the layman often seems to know the difference, so that I was rather surprised to find a Professor of Environmental Sciences using the title 'Global Climate Change' for a collection covering these and other disparate topics. There are even two chapters on 'nuclear winter' (remember that?), perhaps the most obviously dated — though in fact most of the contributions seem four or five years old. The piece I found most fresh was Rowland's on the ozone hole, first published in 1988, and written just as the current synthesis was becoming established. The contrast is marked with the editor's brief chapter following, which argues for the importance of solar cycles rather than CFC levels and predicts global ozone increases for 1987–90.

Professor Singer has chosen to have several of the contributions followed by 'commentaries'. This could be a useful way of exploring the uncertainties of current science, especially where strongly differing views are held by people who genuinely know a field, but it does require a reasonable knowledge of the area and the ability to commission pieces that will complement one another well. I found the results here inconsistent and unsatisfactory, especially where the book does discuss climate change. The mainstream view is represented by a chapter by Covey on the basics of climate modelling and one by Kellogg on the possible impacts of, and human response to, the predicted climate change due to increased CO_2. The latter does not discuss the physics involved, which makes the next contribution, a lengthy attack on the greenhouse consensus, seem a little out of place as a 'response to Kellogg's paper'. In this, Elsasser mixes statements about the uncertainties in climate modelling and the dangers of bandwagon science, which I trust most scientists in the field would sympathize with, and attacks on the science, or what he believes it to be. Printing this with a detailed refutation could have been an inter-esting didactic exercise complementing a straight presentation of the consensus, but the brief reply-to-the-response just makes some general statements about the complexity and reliability of modern models. An even briefer 'coda' re-emphasizes the uncertainties.

The other commentaries are all short, but have little else in common. One totally ignores the paper it is supposed to be about. Norton's response to Park's detailed description of ocean pollution does not disagree about facts, but shows more optimism about the current situation and the likelihood of action to improve it. Lal's chapter asserting the importance of volcanic and meteoritic dust to climate gets two commentaries, one emphasizing the need for detailed and discriminating study but accepting the reality of such effects, and one arguing that there is no real evidence for their existence at all.

Elsewhere Cicerone provides a good review of atmospheric methane. Stanhill's overview of water management is very clearly written, and if his meteorology seemed perhaps vague at points, this is easily forgiven a man who cites the *Journal of Irreproducible Results*. Mellanby's brief review of acid rain is also very clear, despite emphasizing the complexities, as does Everett's description of surface-water acidification. Two chapters deal with the possibility of artificially mixing the Eastern Mediterranean sea surface to make it warmer in winter and increase rainfall downwind — not an idea I felt had been thought through very thoroughly.

Though I found some contributions well worth reading, and the book is well produced, I hesitate to recommend the collection as a whole. The environmental science student I assume it is aimed at could be harmed as much as helped, unless his reading was carefully directed by a good teacher — who could presumably garner a consistently good reading list at rather less expense. An established scientist wanting a review of an unfamiliar field could benefit from some chapters, but I imagine similar work is available elsewhere.

W.J. Ingram

Books received

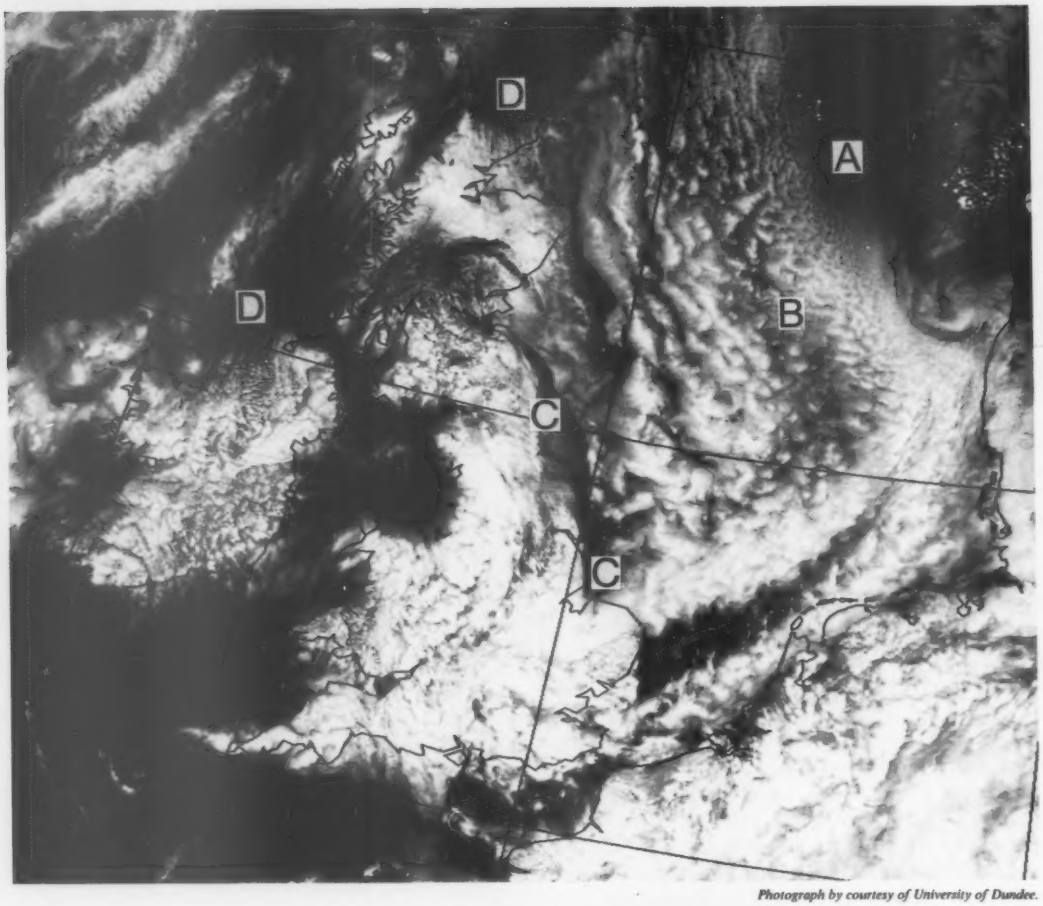
The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Elementary fluid dynamics, by D.J. Acheson (Oxford University Press, 1990) presents the basic physics and mathematics of fluid motion in a form for newcomers to the subject. Topics covered include viscid and inviscid flow, vorticity, waves, aerofoil theory and boundary layers.

Applied environmetric meteorological tables, by T. Beer (Balwyn, Melbourne, Applied Environmetrics, 1990) contains a variety of tables for meteorological use (on an accompanying disk). The 5.25-inch disk will run on IBM compatible computers which has DOS 2.10 or later and at least 256K of RAM.

Climatic atlas of the Indian Ocean. Part III: Upper-ocean structure, by S. Hastenrath and L.L. Greischar (The University of Wisconsin Press, 1990) contains calendar monthly maps of various oceanic parameters at standard depth levels. This third volume is intended as a further contribution to the exploration of ocean climate.

Satellite photograph — 13 June 1990 at 1330 UTC



Photograph by courtesy of University of Dundee.

Figure 1. NOAA-11 visible image on 13 June 1990 at 1330 UTC. The labelling A–D is referenced in the text.

The NOAA-11 AVHRR visible image shown here (Fig. 1) was taken during a period of cool northerly winds and generally persistent cloud cover over the British Isles and North Sea (Fig. 2).

Convection was limited by a marked subsidence inversion near 850 hPa with the cloud a combination of shallow cumulus and more extensive sheets of stratocumulus. Considerable detail can be seen in the scale of cellular convection. Note the increase in cell size from A to B over the North Sea. Marked variations in cloud thickness can also be clearly discerned. The band of much thinner and less textured cloud near to the east coast at C may be due to low-level divergence and sinking motion induced by the land–sea temperature contrast.

Overland, narrow cumulus streets can be seen at D aligned with the low-level northerly flow.

A.J. Waters

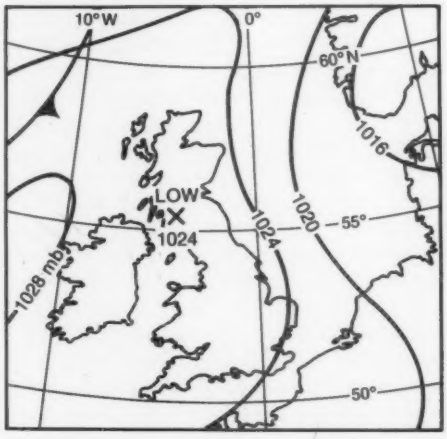


Figure 2. Surface analysis on 13 June 1990 at 1200 UTC.

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Preparation and submission of articles

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately. Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

References should be made using the Harvard system (author/date) and full details should be given at the end of the text. If a document is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to, except by 'personal communication'.

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